Extreme Weather Events

Are they Influenced by Rising Atmospheric CO_2?

Craig D. Idso, Ph.D.

Center for the Study of Carbon Dioxide and Global Change

10 September 2014

Extreme Weather Events:
Are they Influenced by Rising Atmospheric CO_2?

By
Craig D. Idso, Ph.D.
Center for the Study of Carbon Dioxide and Global Change

Abstract

Multiple climate models project that rising atmospheric carbon dioxide concentrations will increase the frequency and/or severity of a number of extreme weather events. This projection has been accepted as fact by numerous scientific organizations and government agencies, including the U.S. EPA. Such claims, however, often fail to stand up against appropriate scientific scrutiny. When key principles of scientific inquiry are adequately addressed and followed, the model projections are consistently seen to conflict with real-world observations, indicating it is highly unlikely that increasing temperatures—whether or not they are driven by rising atmospheric CO_2—will increase the frequency and/or magnitude of severe weather events. In fact, most evidence to date suggests an opposite effect, where rising temperatures would produce less frequent and less severe extreme weather.

Citation: Idso, C.D. 2014. Extreme Weather Events: Are they Influenced by Rising Atmospheric CO_2? Center for the Study of Carbon Dioxide and Global Change, Tempe, AZ. http://www.co2science.org/reports/extremewx/extremewx.pdf.

Table of Contents

1. Introduction

The lexicon used to describe and frame the public debate over the potential impacts of rising carbon dioxide (CO_2) emissions on Earth's climate and biosphere has changed over the years from *global warming* to *climate change* to *extreme weather*. Such phrases, however, are woefully simplistic in their ability to accurately portray and capture the multitude of complexities, intricacies, and nuances associated with a multifaceted subject that spans several academic disciplines, yet they have been effectively used to communicate a desired message and to shape both public opinion and policy.

The term "global warming" originated from computer model studies conducted over three decades ago that projected rising atmospheric CO_2 concentrations would alter important energy transfer processes in the Earth-ocean-atmosphere system and cause a significant warming of the globe that would lead to a host of other environmental changes, including the melting of substantial portions of the polar ice caps, rising sea levels, super-hurricanes, and devastating floods and droughts. Because rising temperatures were often predicted to cause changes in these and other environmental variables, "global warming" became the generic term to describe *all* resultant impacts that might arise from an increase in CO_2. Those who accept this "global warming" hypothesis are known as *climate alarmists* because they are alarmed about these potential impacts. Those who challenge it are referred to as *climate skeptics*.

Public acceptance and use of the phrase "global warming" could not have pleased the climate alarmists more, for it effectively reduced the battle of public opinion and policy debate of an incredibly complex subject to just one parameter—temperature. And because the average person has very limited knowledge of the physics and processes that influence climate, it was relatively easy for a large portion of the public to assume that they could evaluate and judge the merits of the very complex global warming debate by the sole measure of global temperature. And with the temperature record showing a marked increase since the mid-1970s, it was a fairly simple leap for many individuals (including a number of scientists) to accept the hypothesis that the late 20^{th} century rise in temperature was caused by rising atmospheric CO_2 and that all the model-based projections associated with global warming were likely true.

By the early 21^{st} century, however, observations from satellite data made it clear that global temperatures had plateaued, despite increasing emissions of CO_2 into the atmosphere. As a result, public support for policy initiatives to combat global warming began to wane. In an effort to avert this slide in public opinion, climate alarmists began to supplant their use of the phrase *global warming* with the new axiom of *climate change*.

Shifting public conversation away from global warming toward climate change was an important tactical move, as it allowed climate alarmists the opportunity to expand their narrative beyond temperature. Up until this time, in claiming the modern rise in CO_2 was the cause of modern global warming, climate alarmists had effectively limited "proof" of their thesis to the global temperature record for an unsuspecting and largely uneducated public on this topic. It was a brilliant strategy that worked flawlessly when global temperatures cooperated and rose during the 1980s and 90s, but it failed miserably when temperatures plateaued in the new millennium.

One of the most damning arguments put forth at that time against global warming alarmism was a graph of temperature projections derived from climate models that were plotted alongside real-world observations. As shown in Figure 1, this plot reveals a growing divergence between the two as time proceeds. This illustration resonated well with a large portion of the public who began to question in larger and larger numbers how the climate alarmist thesis could be correct if the singular measure by which they had been preconditioned to judge it by, i.e. global temperature, failed to rise in the manner predicted by the models? Simply put, it couldn't be right; and opinion polls began to show the public abandoning their support of the climate alarmist position in droves. Thus, a new narrative had to emerge if the global warming hypothesis was to survive this challenge. And so there was another shift where "global warming" was replaced with "climate change." However, there would still be a challenge in getting the public to accept this new lexis and revert back to supporting the climate alarmist position. And fortunately for them, there was a near endless supply of politicians and members of the media who were all too anxious to promote the word switch … and make it stick.

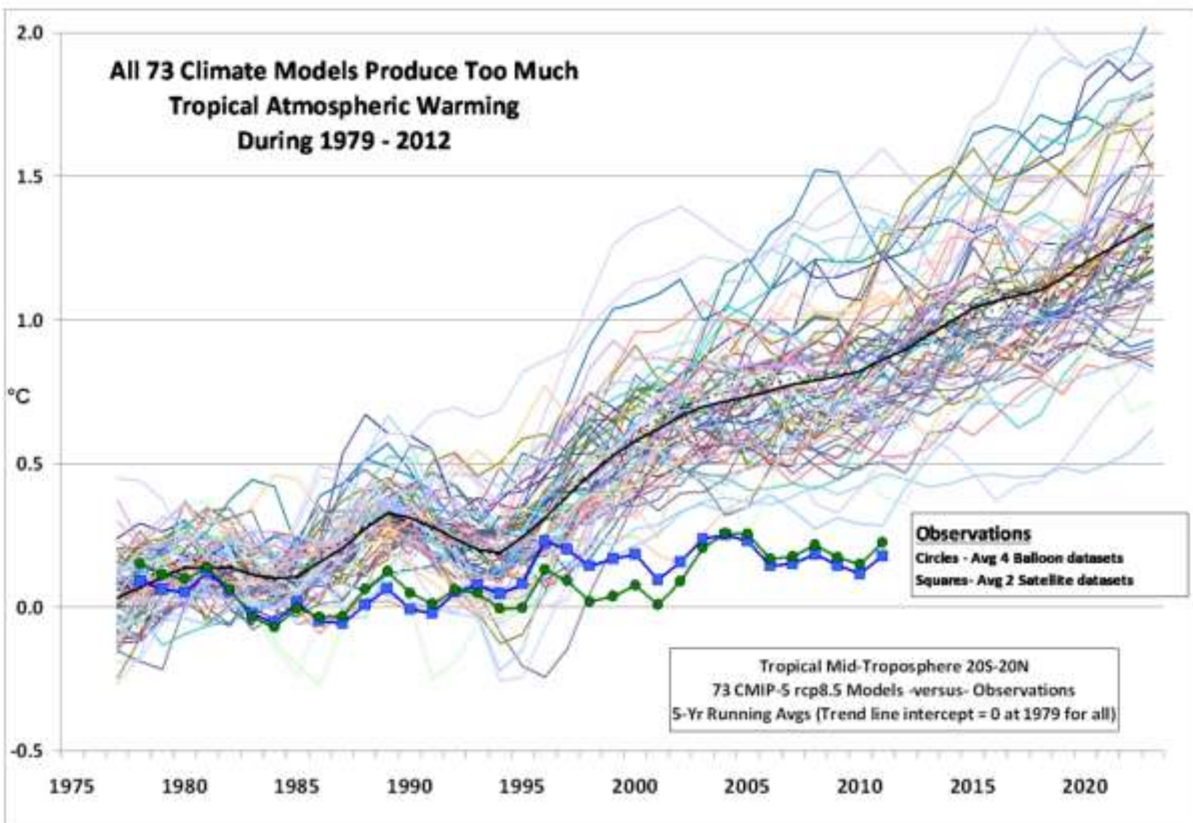

Figure 1. *Mid-tropospheric (MT) temperature variations for the tropics (20°N to 20°S) in 73 current (CMIP5) climate models versus measurements from two satellite datasets and four weather balloon datasets. From Spencer (2013).*

Replacing public expression of the term "global warming" with "climate change" provided climate alarmists with two important advantages in the battle with climate skeptics over public opinion. First, the new phrase now allowed them wiggle room if temperatures failed to rise or even cooled. Previously, under global warming, if temperatures plateaued or fell the jig was up. With climate change it no longer mattered if temperature observations failed to match model projections. Regardless of whether global temperatures warmed or cooled, the new terminology implied that rising CO_2 could be the cause of both!

A second important advantage was that the new phrase allowed climate alarmists the opportunity to expand their narrative with the public beyond temperature. Now, other measures of climate could be trumpeted and heralded before the public as additional proofs of so-called "climate change." It allowed them to take a parameter such as Arctic ice volume, for example, and claim something like "its downward trend over the past three decades is clear evidence of climate change." As explicitly presented, the statement above is correct. Even climate skeptics would be forced to admit as much. Sea ice volume in the Arctic has indeed declined in recent years as a result of *some* change in climate. However, the statement is also grossly misleading, for it says nothing about the *cause* of the sea ice decline. The decline in Arctic sea ice *could* be caused by CO_2-induced global warming, but it could just as well be caused by *natural* warming, or by changes in ocean or atmospheric circulation, winds, precipitation, albedo, or other factors, many of which can and do change naturally and independently of the air's CO_2 content. It is thus disingenuous to intimate that CO_2 is driving a change in a particular climatic parameter without explicitly stating so or providing any real-world proof. Nevertheless, climate alarmists have been waging such a campaign and they have been quite successful in cajoling the public to accept the premise that *any* climate change during the modern era is largely the consequence of the concomitant rise in atmospheric CO_2. And success on this front has emboldened them to take the more recent and controversial leap of linking *extreme weather* events with rising CO_2.

Turing the debate toward extreme weather events provides an additional advantage of playing on the public's short-term memory, for hardly a day goes by in which there is not some extreme weather event causing some sort of danger or damage somewhere on the planet. Thus, there exists a near-endless supply of opportunity for climate alarmists to promote their message on a regular basis. Hurricane Sandy is a good example. When it struck the U.S. Atlantic seaboard in the fall of 2012, notwithstanding evidence from numerous scientific studies that demonstrate there has been no observable increase in Atlantic hurricane frequency or intensity over the past few decades, various media, politicians and scientists were quick to claim the hurricane was caused by rising greenhouse gases in the atmosphere. Others were slightly more reserved. Although not willing to go so far as to assert Sandy was caused by CO_2-induced global warming/climate change, they promoted the alarmist narrative and rhetoric by asserting more such storms could be expected in the future if CO_2 emissions continue to rise.

Nowadays, hardly any extreme weather event passes without someone somewhere claiming it was either caused or made worse by rising CO_2; and it is shortly followed by demands for regulatory action to reduce CO_2 so as to avoid such occurrences in the future. These petitions nearly always reach the ears of United States Environmental Protection Agency, who in June of this year unveiled a Clean Power Plan aimed at reducing emissions of carbon dioxide from the nation's power sector by 30% (relative to 2005 levels) by the year 2030. One of the primary reasons for justifying this action was their stated concern that rising CO_2 will increase the frequency and severity of extreme weather events.

Yet, for all their brilliance in shifting the public's focus on this issue from global warming to climate change, climate alarmists made a tactical mistake in moving the battlefront to extreme weather.

The only way to test the model projections of CO_2-induced climate change is to wait a sufficient period of time before the projections can be compared with observations. Because climate, by definition, is the long-term average of day-to-day weather fluctuations, literally decades can be required before enough observations are collected to enable a proper evaluation of the model projections. This allows climate alarmists a period of years to decades in which they can actively promote their claims without ever being held accountable by observations. The tactical mistake they made in claiming that rising CO_2 will increase the frequency and severity of extreme weather events, however, is that they can be held accountable for this assertion *now*; for empirical analyses can be readily performed to test the correctness of this thesis by examining how extreme weather events have changed (or not changed) in response to the approximate 40% rise in atmospheric CO_2 since the Industrial Revolution.

The present work conducts just such an analysis, examining trends in extreme weather events over the historical past using instrumental observations and paleoclimate proxies. It is prefaced by a discussion of three fundamental principles that must be followed in order to properly deduce a scientific link between rising CO_2 and extreme weather, principles that climate alarmists consistently ignore in their attribution of recent extreme weather events to CO_2-induced climate change. Thereafter, the work provides a detailed analysis of trends in three key categories of extreme weather events, floods, droughts, and storms, finding no compelling evidence to support the claim of a CO_2-indcuded influence on these extreme weather events. Scientific analysis and observation prove otherwise. Claims that global warming or climate change are causing or will cause an increase in these key extreme weather occurrences, therefore, amount to nothing more than a deceitful public relations ploy designed to confuse and scare the public into supporting regulatory actions aimed at reducing CO_2 emissions. Rising atmospheric carbon dioxide is not making extreme weather worse and reducing the air's CO_2 content will not cause the frequency or intensity of such events to diminish.

2. How to Properly Test for a CO_2-induced Influence on Extreme Weather

The scientific method is a tried and true means by which hypotheses can be formulated, tested, and evaluated. The first step in the method is to observe and conduct background research on a particular topic or scientific question. Next, based on initial observations and research, an hypothesis is created to supposedly explain the phenomenon under examination. Then, it is tested via a series of properly designed and controlled experiments, after which the information gleaned from the experiments is studied and evaluated, leading to a conclusion that either supports or refutes the original hypothesis.

For centuries this method has provided the physical and natural sciences with the means to critically gather information and expand knowledge. The scientific method is also highly applicable in investigations of the potential causes and consequences of climate change. However, it is frequently misapplied in attributing extreme weather events to CO_2-induced global warming. This section examines three critical principles that are often overlooked in reaching that attribution (see Figure 2). Failure to observe any one of these principles generally invalidates all CO_2-related attribution claims. When properly applied, in most (if not all) instances, claims that extreme weather events are increasing in frequency and severity because of rising CO_2 fail to be substantiated.

Three Steps to Identifying a CO_2-induced Influence on Extreme Weather Events

1. Pertinent data must be obtained across a sufficiently long period of time.
2. The natural variability of the parameters involved must be appropriately analyzed.
3. The influence of all non-CO_2-driven variables that might impact an extreme weather event must be determined and removed from observable trends.

Figure 2. *A list of three principles that must be followed in order to ascertain a CO_2-induced global warming effect on extreme weather events. Failure to follow any of these principles effectively invalidates claims of a CO_2 link.*

2.1. Obtain Proper Data Over a Sufficient Time Period

As shown in Figure 2, the first step in properly attributing a given extreme weather event to CO_2-induced global warming is to obtain real, measurable data on that event over a sufficiently long time period. This rule may seem rather obvious, yet time and again many scientists, politicians and members of the media violate this principle and publically intimate there exists a CO_2-induced global warming influence on extreme weather simply because climate models *project* an influence. These individuals fail to recognize the basic truth that climate model projections are not of the same standard as real world observations. In fact, model output is unquestionably far inferior.

Still, climate models are important tools utilized to advance our understanding of current and past climate. They also provide both qualitative and quantitative information about potential future climate. But in spite of their sophistication, they remain just that—models. They are nothing more than simulations of the real world, constrained in their ability to correctly capture and portray each of the important processes that operate across multiple spatial and temporal domains to affect climate. By their very nature, climate models deal in the *hypothetical*. Their output amounts to nothing more than projections of future *possibilities*; and as such, model output can never substitute for real-world observations, especially when attempting to discern a CO_2-induced influence on extreme weather.

It is also worth pointing out another weakness of climate models. The average person has little to no knowledge concerning the inner workings and limitations that exist in present-day state-of-the-art climate models. Few people are aware that although the models are quite sophisticated, they are also replete with numerous inadequacies and biases. And although such shortcomings are frequently documented in the peer-reviewed scientific literature, these imperfections rarely find their way into public discourse.

A partial assessment of model inadequacies was recently conducted and published in a major report of the Nongovernmental International Panel on Climate Change (NIPCC). Notwithstanding their admirable complexities, the NIPCC scientists found the models to be deficient in many aspects of their portrayal of climate, leading them to strongly question their ability to provide reliable simulations of the future (Idso *et al*., 2013).

One example of such deficiencies was presented earlier in Figure 1, where simulated global temperatures from 73 models are plotted against mid-tropospheric observed temperatures over the past three and a half decades. The universal failure of the models to correctly project global temperature over this time period is shocking, especially since *global temperature* is the single most important variable examined in all the models because of its expectation to rise as the air's CO_2 content increases. No other variable receives as much attention. Yet, the models failed to correctly project global temperature over the past three decades. So how in the world can they be expected to produce reliable simulations of *extreme weather events* decades to *centuries* into the future? Simply put, they cannot. It is intrinsically much more difficult to simulate extreme weather events—which operate within much smaller spatial and temporal domains—than it is to simulate average global temperature.

Confidence in a model is based on the careful evaluation of its performance against actual observations. Because models fail to accurately simulate what is arguably supposed to be the *simplest* of all climatic variables—global temperature—confidence in their ability to simulate more complex events, such as is required with extreme weather, must be greatly tempered.

Recognizing that climate model output is no substitute for real-world data, scientists must turn to *observations* in their efforts to prove or disprove any CO_2-induced influence on extreme weather events. And that requires datasets that have been in existence for long periods of time, datasets which are of sufficient length to adequately discern whether or not recent changes in extreme weather parameters have stretched beyond their known realm of natural variability. And this leads to the second principle presented in Figure 2: *The natural variability of the parameter must be studied and known*.

2.2. Natural Variability Must be Studied and Known

Aside from model projections of the *future*, multiple scientific organizations and government agencies, including the U.S. EPA, contend that CO_2-induced global warming is causing an increase in the frequency and/or magnitude of extreme weather events *now*. Far too often these groups point to the occurrence of a recent extreme weather event and claim it was either directly or indirectly caused by rising temperatures that result from rising atmospheric CO_2.

The correctness of such claims can be evaluated rather simply by analyzing trends in extreme weather events over the historic past. If the observational data show *no trend*, or if they *decline* over time toward the present, the hypothesis that rising CO_2 is increasing the frequency and/or magnitude of the events can be falsified. For under such circumstances, it cannot be concluded that rising CO_2 is having any measurable effect on the extreme weather event under examination. Yet it is a bit more complicated than that.

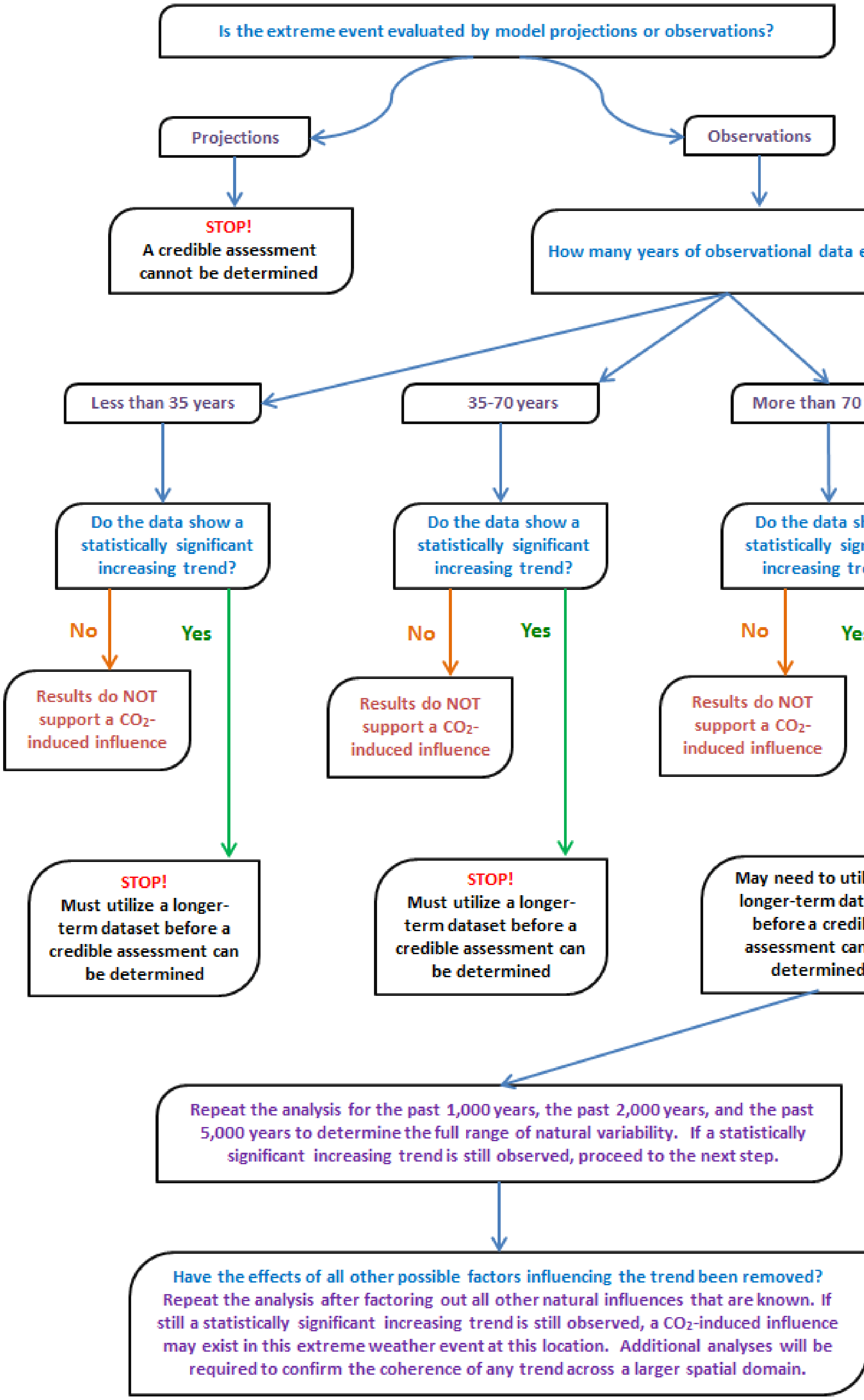

Figure 3. *Flow chart detailing questions that must be addressed and steps that must be taken to perform a proper analysis to test the model-based hypothesis that rising CO_2 concentrations are increasing the frequency and severity of extreme weather events.*

Figure 3 presents a flow chart of the many questions that must be asked, and the steps that must be followed, before one is able to properly test the CO_2-induced increase in extreme weather hypothesis. A critical step in this process centers on obtaining datasets of sufficient length to conduct proper statistical analyses. False signals can be obtained if a dataset is too short. Determining what constitutes a sufficiently long dataset begins with an understanding of how atmospheric CO_2 and global temperature have changed over time.

Atmospheric carbon dioxide concentrations have been rising since the dawn of the Industrial Revolution. Driven by gaseous emissions from the burning of fossil fuels such as coal, gas and oil, the air's CO_2 content has risen from a mean concentration of about 280 parts per million (ppm) in 1800 to a value of approximately 400 ppm today. This historic rise in CO_2, however, has not been uniform. Half of the increase has occurred since 1980 and three-fourths has occurred since the end of World War II (WWII). Therefore, if rising CO_2 is having an effect on extreme weather, testing for such requires examination of extreme weather events that have occurred over a period of time in which a large fraction of the modern buildup of CO_2 has occurred. Though it is perhaps somewhat subjective to designate at what point in time the rise in CO_2 constitutes a "large fraction" of the modern increase, a good starting point would be since the end of WWII (~70 yrs), as three-fourths of its modern increase occurred since that time. However, because many extreme weather datasets do not extend back in time 70 years, a secondary starting option would be some interval of time between the end of WWII and 1979, as half of the modern increase in atmospheric CO_2 has occurred during the past 35 years. If no trend or a declining trend in the data is observed over either of these two periods, the hypothesis that a given extreme weather event is affected by the rise in CO_2 cannot be verified, and is more likely falsified.

But what if a *rising* trend were observed in the data, would that be proof of a CO_2-induced influence? In a word, no. As shown in Figure 3, additional analyses must be performed.

It has already been established that, at a minimum, trends in extreme weather events must be evaluated over the period of majority buildup of CO_2, which logically could be interpreted as the three-fourths increase that has occurred since the end of WWII or the one-half increase since 1979. If a *rising* trend is observed over this period, the parameter must further be examined over a much longer time period from which the full expression of its natural variability can be observed. And because extreme weather events are projected to increase in consequence of CO_2-induced global *warming*, the only way to obtain an untainted view of their natural variability is to examine how these events responded to changes in climate over similar warm periods prior to the modern buildup of anthropogenic CO_2. In most cases, this requires extending datasets back in time approximately 1,000 years to a climatic period known as the Medieval Warm Period, which was the last time global temperatures reached levels as warm as—or warmer than—they are today. Nevertheless, shorter datasets may still be used to *falsify* the CO_2-induced extreme weather hypothesis, they just can't be used to prove it. Though a record may only extend back in time 200, 300, or 500 years, if it shows no trend or a declining trend, the hypothesis of a CO_2-induced influence can be rejected.

The example below illustrates the importance of tempering claims of a CO_2-induced influence on extreme weather events of the modern era and the need to study and evaluate their occurrence over a much longer period where the full expression of natural variability can be observed.

According to John Hooper's 14 August 2002 article in *The Guardian*, in the midst of that year's massive flooding in Europe, Gallus Cadonau (the managing director of the Swiss Greina Foundation) called for a punitive tariff on U.S. imports to force cooperation on greenhouse gas emissions, claiming that the flooding "definitely ha[d] to do with global warming" and stating that "we must change something now." He was joined in this sentiment by Germany's environment minister, Jurgen Trittin, who implied much the same thing when he said "if we don't want this development to get worse, then we must continue with the consistent reduction of environmentally harmful greenhouse gasses." A thorough analysis of historical flood accounts and more recent river-flow data by Mudelsee *et al*. (2003), however, revealed something very different.

What this team of German researchers did was to analyze historical documents stretching from the 11th century to 1850 and subsequent water stage and daily runoff records from then until 2002 pertaining to two of the largest rivers in central Europe, the Elbe and Oder rivers, seeking to determine trends in flood occurrence over the past thousand years. In so doing, the scientists report that "for the past 80 to 150 years"—which climate alarmists typically describe as a period of unprecedented CO_2-induced global warming—"we find a decrease in winter flood occurrence in both rivers, while summer floods show no trend, consistent with trends in extreme precipitation occurrence." Thus, the strident claims of Cadonau and Trittin that global warming had caused the 2002 flooding failed to stand up to scrutiny when compared with historical observations. As the world recovered and warmed from the global chill of the Little Ice Age, flooding of the Elbe and Oder rivers did *not* materially change in summer and actually *decreased* in winter.

Blaming anthropogenic CO_2 emissions for the European flooding of 2002 was obviously incorrect and not a reasoned deduction based on scientific evidence. If Cadonau and Trittin had properly followed the steps outlined in Figure 3, they would not have gotten things so wrong.

The dilemma and difficulty in most analyses of extreme weather events, however, is that modern records do not extend back that far in time. Indeed, most datasets only go back a few decades, rarely eclipsing a century in length. Thus, proxy records of extreme weather events must be collected and studied. And that is not easy to do. They take time and effort, and they are costly to produce. Nevertheless, they are necessary for those desiring to conduct proper scientifically-based analyses of extreme weather events.

At this point, as illustrated in Figure 3, it should also be noted that even if a location yields a positive trend in an extreme weather event across a time period of over 1,000 years or more, such a finding is still not sufficient to validate the model-based claims; for the mere existence of a positive trend does not prove it was caused by CO_2-induced influences. And that brings up the third and final step required to properly establish a CO_2 effect on extreme weather events: *The influence of all other (non CO_2-driven) variables that impact a given extreme weather event must be studied and factored out of observable trends*.

2.3. Non CO_2-driven Impacts Must be Resolved and Removed

Anyone with limited knowledge of statistics knows that correlation among variables does not prove causation, and anyone with a limited understanding of weather and climate knows there are many factors that can cause extreme weather events. Natural forcings and factors operate across multiple timescales and varying spatial domains to cause extreme weather; and they have been doing it independent of the air's CO_2 concentration for eons.

Consider, for example, the following analysis of extreme river levels and flows of the Nile River by Kondrashov *et al*. (2005). For their analysis, they applied advanced spectral methods to fill in data gaps and locate interannual and interdecadal periodicities in historical records of annual low- and high-water levels of the Nile River over the 1,300-year period A.D. 622 to 1922. In doing so, they found several statistically significant periodicities in the record, including cycles of 256, 64, 19, 12, 7, 4.2, and 2.2 years. With respect to the *causes* of these cycles, Kondrashov *et al*. say the 4.2- and 2.2-year oscillations are likely the product of El Niño-Southern Oscillation variations. The 7-year cycle, on the other hand, is possibly related to North Atlantic influences, according to them, while the longer-period oscillations may be due to astronomical forcings.

In addition to revealing the stated periodicities, the results of Kondrashov *et al*.'s analysis and annual-scale resolution provide what they refer to as a "sharper and more reliable determination of climatic-regime transitions" for tropical east Africa, including documentation of fairly abrupt shifts in river flow at the beginning and end of the Medieval Warm Period, as well as for other periods throughout the record. These "fairly sharp shifts in the amplitude and period of the interannual and interdecadal modes over the last millennium-and-a-half," according to the researchers, "support concerns about the possible effect of climate shifts in the not-so-distant future."

Thus, those living near the Nile and who are dependent on it for their sustenance should be particularly concerned, for abrupt changes in flow rates and river levels have punctuated the river system for 1,300 years or more; and there is no reason why similar changes will not continue in the future, independent of any change in atmospheric CO_2 concentration.

If and when the situation does change and the Nile flow rates and river levels experience extreme events, these natural periodicities would have to be accounted for and subtracted out before any attribution could properly be ascribed to rising CO_2. The same is true for all indices of extreme weather. The burden of proof remains with the climate alarmists who must demonstrate that the influence of all other potential factors have been removed and ruled out as possible cause(s) of an extreme weather event increase before they can ascribe its rise to CO_2. Unfortunately, many climate alarmists are not content to do this required work; and they therefore have no business making attribution claims that have not been properly vetted.

Furthermore, it is also important to note that results from one analysis in one location do not a *global* conclusion make. Similar trends from *multiple* locations around the globe are needed before a true assessment of the extreme weather hypothesis can be made. Fortunately, numerous such studies have been conducted according to the principles and steps outlined above; and they have been published in the peer-reviewed scientific literature, providing a fairly complete assessment of the entirety of the climate-alarmist hypothesis. The following section analyzes a significant portion of that literature, presenting a compelling refutation of the claim that CO_2-induced global warming is increasing the frequency and severity of three key extreme weather phenomena.

3. Extreme Weather Observations and Trends

Numerous studies have been conducted over the past decade or so that allow evaluation of the claim that CO_2-induced global warming is increasing both the frequency and intensity of various types of extreme weather events. A recent report by the Nongovernmental International Panel on Climate Change (NIPCC), for example, highlights the findings of over 1,000 scientific papers that have examined this assertion (Idso *et al*., 2013). That report concludes there is nothing unusual, unnatural, or unprecedented about extreme weather events of the past few decades, and that the ongoing rise in the atmosphere's CO_2 concentration is having no measurable influence on these phenomena. A similar conclusion is reached here.

The subsections below highlight the findings of several scientific investigations into three of the most often examined types of extreme weather events: floods, droughts, and storms. Collectively, these studies demonstrate the importance of following the three steps outlined in Figure 2, and correctly navigating the flow chart of procedures presented in Figure 3, in order to properly test for a CO_2-induced influence on these extreme weather events. For those desiring additional evidence that anthropogenic CO_2 emissions are having a negligible impact on extreme weather beyond the three event categories examined here, please see the *Extreme Weather* chapter from the aforementioned NIPCC report that can be downloaded at http://www.nipccreport.org/reports/ccr2a/pdf/Chapter-7-Extreme-Weather.pdf.

3.1. Floods

Multiple researchers have investigated how flood activity has changed over the recent past and how this extreme weather event has responded to the global warming of the past several decades. Their analyses provide a means of evaluating climate-alarmist claims that CO_2-induced global warming is leading to more frequent and intensified flooding around the globe; and they indicate there is nothing unusual about the flooding of the modern era. Large flood events occurring in recent times have many historic analogs in the past, when air's CO_2 concentration was much lower than it is presently. Taken together, the material presented in this section strongly suggests that rising atmospheric CO_2 is having no measurable impact on modern flood events.

3.1.1 Trends of the Past Century

The first step in evaluating claims that rising CO_2 is causing more frequent and severe flooding begins with a rather simple analysis of flood events over the past few decades during which time the bulk of anthropogenic CO_2 accumulated in the atmosphere. If the observational data show no trend in flood events, or if they are shown to decline over this period, the hypothesis that rising CO_2 is increasing the frequency and/or magnitude of these events can be falsified, as such findings contradict the hypothesis. This section thus examines the results of several scientific studies that have performed this initial phase of flood uniqueness evaluation.

Starting in North America, Lins and Slack (1999) analyzed secular streamflow trends in 395 different parts of the United States that were derived from more than 1,500 individual stream gauges, some of which had continuous data stretching all the way back to 1914. In the mean, they found "the conterminous U.S. is getting wetter, but less extreme." That is to say, as the near-surface air temperature of the planet gradually rose throughout the course of the 20th century, the United States became wetter in the mean but less variable at the extremes, which is where floods and droughts occur, leading to what could well be called the best of both worlds, i.e., more water with less floods, which findings are just the *opposite* of routine climate-alarmist claims.

In a more regionally-focused study, Molnar and Ramirez (2001) conducted a detailed analysis of precipitation and streamflow trends for the period 1948-1997 in the semiarid Rio Puerco Basin of New Mexico. At the annual timescale, they reported finding "a statistically significant increasing trend in precipitation," which was driven primarily by an increase in the number of rainy days in the moderate rainfall intensity range, with essentially no change at the high-intensity end of the spectrum. In the case of streamflow, however, there was no trend at the annual timescale; but monthly totals increased in low-flow months and decreased in high-flow months, once again reducing the likelihood of both floods and droughts during the warming of the 20th-century.

With respect to the implications of these findings, increased precipitation in a semiarid region is a major benefit. Having most of the increase in the moderate rainfall intensity range is also a plus. Increasing streamflow in normally low-flow months sounds good too, as does decreasing streamflow in high-flow months. In fact, *all* of the observed changes in precipitation and streamflow in this study would appear to be highly desirable, leading to more water availability but a lowered probability of both floods and droughts, which suggests the best of *all* worlds.

Knox (2001) identified an analogous phenomenon in the more mesic Upper Mississippi River Valley. Since the 1940s and early 50s, the magnitudes of the largest daily flows in this much wetter region have been decreasing at the same time that the magnitude of the average daily baseflow has been increasing, once again manifesting simultaneous trends towards both lessened flood and drought conditions, which again is just the *opposite* of climate-alarmist claims.

Much the same story is told by the research of Garbrecht and Rossel (2002), who studied the nature of precipitation throughout the U.S. Great Plains over the period 1895-1999. For the central and southern Great Plains, the last two decades of this period were found to be the longest and wettest of the entire 105 years of record, due primarily to a reduction in the number of dry years and an increase in the number of wet years. However, the number of *very wet years*—which would be expected to produce flooding—"did not increase as much and even showed a decrease for many regions," as they put it. The northern and northwestern Great Plains also experienced a precipitation increase near the end of Garbrecht and Rossel's 105-year record; but it was primarily confined to the final decade of the 20th century. And again, as they report, "fewer dry years over the last 10 years, as opposed to an increase in very wet years, were the leading cause of the observed wet conditions."

Writing as background for their work, Hirsch and Ryberg (2012) state that "one of the anticipated hydrological impacts of increases in greenhouse gas concentrations in the atmosphere is an increase in the magnitude of floods," citing Trenberth (1999), the IPCC (2007) and Gutowski *et al*. (2008); and they therefore set out to see if such might have occurred across the United States over the past century or so.

Working with the global mean carbon dioxide concentration (GMCO2) and a streamflow data set that consisted of long-term (85- to 127-year) annual flood series from 200 stream gauges that had been deployed by the U.S. Geological Survey in basins with little or no reservoir storage or urban development (less than 150 persons per square kilometer in AD 2000) throughout the coterminous United States—which they divided into four large regions—Hirsch and Ryberg employed a stationary bootstrapping technique to determine if the patterns of the statistical associations between the two parameters were significantly different from what would be expected under the null hypothesis that flood magnitudes are independent of GMCO2.

In describing their findings the two researchers report that "in none of the four regions defined in this study is there strong statistical evidence for flood magnitudes increasing with increasing GMCO2." In fact, they say that one region, the southwest, showed a statistically significant negative relationship between GMCO2 and flood magnitudes. As such, Hirsch and Ryberg conclude "it may be that the greenhouse forcing is not yet sufficiently large to produce changes in flood behavior that rise above the 'noise' in the flood-producing processes." On the other hand, a simpler conclusion is that the "anticipated hydrological impacts" envisioned by the IPCC and others are simply incorrect.

In another study, Villarini and Smith (2010) "examined the distribution of flood peaks for the eastern United States using annual maximum flood peak records from 572 U.S. Geological Survey stream gaging stations with at least 75 years of observations." This work revealed (1) "only a small fraction of stations exhibited significant linear trends," (2) "for those stations with trends, there was a split between increasing and decreasing trends," and (3) "no spatial structure was found for stations exhibiting trends." Thus, they concluded, most importantly of all, that "there is little indication that human-induced climate change has resulted in increasing flood magnitudes for the eastern United States," providing no support for the claim that global warming will lead to more frequent, more widespread, and more serious floods.

Much the same has been reported for Canada. Cunderlik and Ouarda (2009) evaluated trends in the timing and magnitude of seasonal maximum flood events across that country, based on data obtained from 162 stations of the Reference Hydrometric Basin Network established by Environment Canada over the 30-year period 1974 to 2003. In spite of the supposedly unprecedented warming experienced over the period of time they studied, the Canadian researchers report that "only 10% of the analyzed stations show significant trends in the timing of snowmelt floods during the last three decades (1974-2003)," and they say these results imply "the occurrence of snowmelt floods is shifting towards the earlier times of the year," as would be expected in a warming world. However, they note most of the identified trends "are only weakly or medium significant results," and they add that "no significant trends were found in the timing of rainfall-dominated flood events."

With respect to flood magnitudes, the two scientists state the trends they observed "are much more pronounced than the trends in the timing of the floods," but they say that most of these trends "had negative signs, suggesting that the magnitude of the annual maximum floods has been decreasing over the last three decades." In addition, they found that "the level of significance was also higher in these trends compared to the level of significance of the trends in the timing of annual maximum floods."

Working in France, Renard *et al*. (2008) employed four different procedures for assessing field significance and regional consistency with respect to trend detection in both high-flow and low-flow hydrological regimes of French rivers, using daily discharge data obtained from 195 gauging stations having a minimum record length of 40 years. In doing so, they determined that "at the scale of the entire country, the search for a generalized change in extreme hydrological events through field significance assessment remained largely inconclusive." In addition, they discovered that at the smaller scale of hydro-climatic regions, there were also no significant results for most such areas.

According to Korhonen and Kuusisto (2010), "annual mean temperatures in Finland increased by about 0.7°C during the 20th century," citing Jylha *et al*. (2004) and while noting that under such a warming regime "both droughts and floods are expected to intensify." In a study designed to explore the soundness of this contention, the two Finnish researchers analyzed long-term trends and variability in the discharge regimes of both regulated and unregulated rivers and lake outlets in Finland up to the year 2004, using data supplied by the Finnish Environment Institute.

This analysis revealed that as "winters and springs became milder during the 20th century ... the peak of spring flow has become 1-8 days earlier per decade at over one-third of all studied sites." However, they say that "the magnitudes of spring high flow have not changed." On the other hand, low flows, in their words, "have increased at about half of the unregulated sites due to an increase in both winter and summer discharges." Nevertheless, they indicate that "statistically significant overall changes have not been observed in mean annual discharge." Thus, in contrast to typical global warming projections, at the high end where flooding may occur, there has been no change in the magnitude of flows that can lead to that unwelcome phenomenon for the region examined. And at the low end, where droughts may occur, there has actually been an increase in flow magnitude; and that increase either acts to prevent or leads to less frequent and/or less severe episodes of this other unwelcome phenomenon.

Finally, in regard to the IPCC's Special Report on *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, or SREX for short, Kundzewicz *et al*. (2014) conducted a follow-up study to assess "the literature included in the IPCC SREX report and new literature published since," while also examining "changes in flood risk in seven of the regions considered in the recent IPCC SREX report—Africa, Asia, Central and South America, Europe, North America, Oceania and Polar regions." Among the highlights of their work, the team of seventeen researchers hailing from eleven different countries report the following: (1) "no gauge-based evidence has been found for a climate-driven, globally widespread change in the magnitude/frequency of floods during the last decades," (2) "there is *low confidence* in projections of changes in fluvial floods, due to *limited evidence* and because the causes of regional changes are complex," (3) "considerable uncertainty remains in the projections of changes in flood magnitude and frequency," (4) increases in global flood disaster losses reported over the last few decades "may be attributed to improvements in reporting, population increase and urbanization in flood-prone areas, increase of property value and degraded awareness about natural risks (due to less natural lifestyle)," (5) "the linkages between enhanced greenhouse forcing and flood phenomena are highly complex and, up to the present, it has not been possible to describe the connections well, either by empirical analysis or by the use of models," and (6) "the problem of flood losses is mostly about what we do on or to the landscape," which they say "will be the case for decades to come."

In the concluding paragraph of their extensive study, Kundzewicz *et al*. state "although media reports of both floods and global flood damage are on the increase, there is still no Mauna-Loa-like record (see Vorosmarty, 2002) that shows a global increase in flood frequency or magnitude." Thus, they write "blaming climate change for flood losses makes flood losses a global issue that appears to be out of the control of regional or national institutions." And they therefore state "the scientific community needs to emphasize that the problem of flood losses is mostly about what we do on or to the landscape," which implies that individual, community, county and state responsibility "will be the case for decades to come."'

Taken together, the research described in the paragraphs above suggests that, if anything, flooding tends to become both less frequent and less severe when the planet warms, although there have been some exceptions to this general rule. And although there could also be exceptions to this rule in the future, it is more likely that any further warming of the globe would tend to further reduce both the frequency and severity of flooding, which is just the opposite of what climate models suggest should occur under such conditions.

3.1.2. Natural Variability Seen from Long-term, Centennial-scale Studies

Beyond short term analyses of only a few decades, a number of studies have examined flooding over centennial to millennial time scales. These studies, which comprise those reviewed in this section, allow the comparison of flood events that occurred prior to the modern buildup of anthropogenic CO_2 in the air with those that occurred after it. These types of analyses reveal great detail about the breadth and depth of natural variability and are of great value in investigating the potential influence of rising CO_2 on floods.

During the 1990s, broad areas of the US Northern Great Plains experienced notable lake highstands, including Waubay Lake, which rose by 5.7 meters and more than doubled in area from 1993 to 1999, severely flooding roads, farms and towns, and prompting the Federal Emergency Management Agency to declare the region a disaster area on 1 June 1998. Shapley *et al*. (2005) set out to determine the historical context of that 1990s lake-level rise by developing a 1,000-year hydroclimate reconstruction from local bur oak (*Quercus macrocarpa*) tree-ring records and lake sediment cores from the Waubay Lake complex located in eastern South Dakota. In doing so, the researchers found that "prior to AD 1800, both lake highstands and droughts tended towards greater persistence than during the past two centuries," such that "neither generally low lake levels occurring since European settlement (but before the recent flooding) nor the post-1930s pattern of steadily increasing water availability and favorableness for tree growth are typical of the long-term record." In this particular part of the world, therefore, it is clear that longer-lasting floods and droughts of equal or greater magnitude than those of modern times occurred repeatedly prior to 1800 and independent of atmospheric CO_2.

A bit further to the north, significant flooding of the Red River of the North occurred in 1997, which devastated Grand Forks, North Dakota, as well as parts of Canada. However, as Haque (2000) reports, although this particular flood was indeed the largest experienced by the Red River over the past century, it was not the largest to occur in historic times. In 1852, for example, there was a slightly larger Red River flood; and in 1826 there was a much larger flood that was nearly 40% greater than the flood of 1997. And the temperature of the globe, it should be noted, was much colder at the times of these earlier catastrophic floods than it was in 1997, indicating the strength of the 1997 flood cannot be attributed to the degree of warmth experienced that year or throughout the preceding decade.

In a study designed to determine the environmental origins of extreme flooding events throughout the southwestern United States, Ely (1997) wrote that "paleoflood records from nineteen rivers in Arizona and southern Utah, including over 150 radiocarbon dates and evidence of over 250 flood deposits, were combined to identify regional variations in the frequency of extreme floods," which information "was then compared with paleoclimatic data to determine how the temporal and spatial patterns in the occurrence of floods reflect the prevailing climate." The results of this comparison indicated that "long-term variations in the frequency of extreme floods over the Holocene are related to changes in the climate and prevailing large-scale atmospheric circulation patterns that affect the conditions conducive to extreme flood-generating storms in each region," which changes, in Ely's view, "are very plausibly related to global-scale changes in the climate system."

With respect to the Colorado River watershed, for example, which integrates a large portion of the interior western United States, she writes that "the largest floods tend to be from spring snowmelt after winters of heavy snow accumulation in the mountains of Utah, western Colorado, and northern New Mexico," such as occurred with the "cluster of floods from 5 to 3.6 ka," which occurred in conjunction with "glacial advances in mountain ranges throughout the western United States" during the "cool, wet period immediately following the warm mid-Holocene."

The frequency of extreme floods also increased during the early and middle portions of the first millennium AD, many of which coincided "with glacial advances and cool, moist conditions both in the western U.S. and globally." Then came a "sharp drop in the frequency of large floods in the southwest from AD 1100-1300," which corresponded, in her words, "to the widespread Medieval Warm Period, which was first noted in European historical records." With the advent of the Little Ice Age, however, there was another "substantial jump in the number of floods in the southwestern U.S.," which was "associated with a switch to glacial advances, high lake levels, and cooler, wetter conditions." And in distilling her findings down to a single succinct statement, and speaking specifically of the southwestern United States, Ely states that "global warm periods, such as the Medieval Warm Period, are times of dramatic decreases in the number of high-magnitude floods in this region." This conclusion, of course, directly contradicts the climate alarmist hypothesis that warmer temperatures results in increased extreme flood events.

In another study encompassing the entire continental United States, Fye *et al*. (2003) developed multi-century reconstructions of summer (June-August) Palmer Drought Severity Index from annual proxies of moisture status provided by 426 climatically-sensitive tree-ring chronologies. This exercise indicated that the greatest 20th-century wetness anomaly across the United States was the 13-year pluvial that occurred in the early part of the century, when it was considerably colder than it is now. In addition, Fye *et al*.'s analysis revealed the existence of a 16-year pluvial from 1825 to 1840 and a prolonged 21-year wet period from 1602 to 1622, both of which anomalies occurred during the Little Ice Age, when, of course, it was colder still.

Moving to analyses from other countries, on the 8th and 9th of September 2002, extreme flooding of the Gardon River in southern France occurred as half an average year's rainfall was received in approximately twenty hours, which flooding claimed the lives of a number of people and caused much damage to towns and villages situated adjacent to its channel. The event garnered much press coverage; and, in the words of Sheffer *et al*. (2003a), "this flood is now considered by the media and professionals to be 'the largest flood on record'," which record extended all the way back to 1890.

Coincidently, Sheffer *et al*. were in the midst of a study of prior floods of the Gardon River when the "big one" hit; and they had data spanning a much longer time period against which to compare its magnitude. Based on that data as presented in their paper, they reported "the extraordinary flood of September 2002 was not the largest by any means," noting "similar, and even larger floods have occurred several times in the recent past," with three of the five greatest floods they had identified to that point in time occurring over the period AD 1400-1800 during the Little Ice Age. Commenting on these facts, Sheffer *et al*. state that "using a longer time scale than human collective memory, paleoflood studies can put in perspective the occurrences of the extreme floods that hit Europe and other parts of the world during the summer of 2002." And that perspective clearly shows that even greater floods occurred repeatedly during the Little Ice Age, which was the coldest period of the current interglacial and which obviously had nothing to do with atmospheric CO_2.

Working in the same region five years later, Sheffer *et al*. (2008) analyzed geomorphic, sedimentologic and hydrologic data associated with both historical and late Holocene floods from two caves and two alcoves of a 1600-meter-long stretch of the Gardon River, which analysis they hoped would provide a longer and better-defined perspective on the subject. And so it did, as they discovered "at least five floods of a larger magnitude than the 2002 flood occurred over the last 500 years," all of which took place, as they describe it, "during the Little Ice Age." In addition, they note that "the Little Ice Age has been related to increased flood frequency in France (Guilbert, 1994; Coeur, 2003; Sheffer, 2003; Sheffer *et al*., 2003a,b; Sheffer, 2005), and in Spain (Benito *et al*., 1996; Barriendos and Martin Vide, 1998; Benito *et al*., 2003; Thorndycraft and Benito, 2006a,b)."

Introducing their study of the subject, Wilhelm *et al*. (2012) write "mountain-river floods triggered by extreme precipitation events can cause substantial human and economic losses (Gaume *et al*., 2009)," and they say "global warming is expected to lead to an increase in the frequency and/or intensity of such events (IPCC, 2007), especially in the Mediterranean region (Giorgi and Lionello, 2008)." However, they caution that "reconstructions of geological records of intense events are an essential tool for extending documentary records beyond existing observational data and thereby building a better understanding of how local and regional flood hazard patterns evolve in response to changes in climate."

In an effort to obtain this "better understanding," Wilhelm *et al*. analyzed the sediments of Lake Allos, a 1-km-long by 700-m-wide high-altitude lake in the French Alps (44°14'N, 6°42'35"E), by means of both seismic survey and lake-bed coring, carrying out numerous grain size, geochemical and pollen analyses of the sediment cores they obtained in conjunction with a temporal context derived using several radionuclide dating techniques. In doing so, the thirteen researchers, all hailing from France, report their investigations revealed the presence of some 160 graded sediment layers over the last 1,400 years; and they indicate comparisons of the most recent of these layers with records of historic floods suggest the sediment layers are indeed representative of significant floods that were "the result of intense meso-scale precipitation events." Of special interest to the discussion at hand is their finding of "a low flood frequency during the Medieval Warm Period and more frequent and more intense events during the Little Ice Age," which meshes nicely with the results of an analysis of a Spanish lake sediment archive that allowed Moreno *et al*. (2008) to infer "intense precipitation events occurred more frequently during the Little Ice Age than they did during the Medieval Warm Period."

Wilhelm *et al*. additionally state that "the Medieval Warm Period was marked by very low hydrological activity in large rivers such as the Rhone (Arnaud *et al*., 2005; Debret *et al*., 2010), the Moyenne Durance (Miramont *et al*., 1998), and the Tagus (Benito *et al*., 2003), and in mountain streams such as the Taravilla lake inlet (Moreno *et al*., 2008)." But of the Little Ice Age, they say "research has shown higher flood activity in large rivers in southern Europe, notably in France (Miramont *et al*., 1998; Arnaud *et al*., 2005; Debret *et al*., 2010), Italy (Belotti *et al*., 2004; Giraudi, 2005) and Spain (Benito *et al*., 2003), and in smaller catchments (e.g., in Spain, Moreno *et al*., 2008)."

In concluding their report, Wilhelm *et al*. say their study shows "sediment sequences from high altitude lakes can provide reliable records of flood-frequency and intensity-patterns related to extreme precipitation events," closing with the warning that "such information is required to determine the possible impact of the current phase of global warming." And when this warning is heeded, it is clearly seen that the climate-model-inspired claim that global warming will lead to "an increase in the frequency and/or intensity of such events"—would appear to be just the opposite of what is suggested by Wilhelm *et al*.'s real-world study and the real-world studies of the other scientists they cite.

Glur *et al*. (2103) developed "a multi-archive Alpine flood reconstruction based on ten lacustrine sediment records, covering the past 2,500 years" for the European Alps. In discussing their findings the eight researchers report "flood activity was generally enhanced during the Little Ice Age (1430-1850 C.E.; LIA) compared to the Medieval Climate Anomaly (950-1250 C.E.; MCA)." And they say "this result is confirmed by other studies documenting an increased (decreased) flood activity during the LIA (MCA) in the Alps," citing the studies of Schmocker-Fackel and Naef (2010), Czymzik *et al*. (2010), Wilhelm *et al*. (2012) and Swierczynski *et al*. (2012). Thus, for the European Alps, there would appear to be good reason to conclude that any further warming of the globe would *not* lead to flood-induced "increased threats to settlements, infrastructure, and human lives," for real-world data suggest that it is *cooling* that leads to such consequences in that part of the world.

Focusing on the region of southwest Germany, Burger *et al*. (2007) reviewed what is known about flooding in this region over the past three centuries. According to the six scientists, the extreme flood of the Neckar River (southwest Germany) in October 1824 was "the largest flood during the last 300 years in most parts of the Neckar catchment." In fact, they say "it was the highest flood ever recorded in most parts of the Neckar catchment and also affected the Upper Rhine, the Mosel and Saar." In addition, they report that the historical floods of 1845 and 1882 "were among the most extreme floods in the Rhine catchment in the 19th century," which they describe as truly "catastrophic events." And speaking of the flood of 1845, they say it "showed a particular impact in the Middle and Lower Rhine and in this region it was higher than the flood of 1824." Finally, the year 1882 actually saw two extreme floods, one at the end of November and one at the end of December. Of the first one, Burger *et al*. say that "in Koblenz, where the Mosel flows into the Rhine, the flood of November 1882 was the fourth-highest of the recorded floods, after 1784, 1651 and 1920," with the much-hyped late-20th-century floods of 1993, 1995, 1998 and 2002 not even meriting a mention.

"Starting from historical document sources, early instrumental data (basically, rainfall and surface pressure) and the most recent meteorological information," as they describe it, Llasat *et al*. (2005) analyzed "the temporal evolution of floods in NE Spain since the 14th century," focusing particularly on the river Segre in Lleida, the river Llobregat in El Prat, and the river Ter in Girona. This work indicated there was "an increase of flood events for the periods 1580-1620, 1760-1800 and 1830-1870," and they report that "these periods are coherent with chronologies of maximum advance in several alpine glaciers." In addition, it can be calculated from their tabulated data that, for the aggregate of the three river basins noted above, the mean number of what Llasat *et al*. call catastrophic floods per century for the 14th through 19th centuries was 3.55 ± 0.22, while the corresponding number for the 20th century was only 1.33 ± 0.33.

In concluding their paper, the four Spanish researchers say "we may assert that, having analyzed responses inherent to the Little Ice Age and due to the low occurrence of frequent flood events or events of exceptional magnitude in the 20th century, the latter did not present an excessively problematic scenario." However, having introduced their paper with descriptions of the devastating effects of the September 1962 flash flood in Catalonia (over 800 deaths), the August 1996 flash flood in the Spanish Pyrenees (87 deaths), as well as the floods of September 1992 that produced much loss of life and material damage in France and Italy, they hastened to add that the more recent "damage suffered and a perception of increasing vulnerability is something very much alive in public opinion and in economic balance sheets."

Shifting to the area of southeast Spain, Benito *et al*. (2010) reconstructed flood frequencies of the Upper Guadalentin River using "geomorphological evidence, combined with one-dimensional hydraulic modeling and supported by records from documentary sources at Lorca in the lower Guadalentin catchment." The combined palaeoflood and documentary records indicate that past floods were clustered during particular time periods: AD 950-1200 (10), AD 1648-1672 (10), AD 1769-1802 (9), AD 1830-1840 (6), and AD 1877-1900 (10), where the first time interval coincides with the Medieval Warm Period and the latter four time intervals all fall within the confines of the Little Ice Age; and by calculating mean rates of flood occurrence over each of the five intervals, a value of 0.40 floods per decade during the Medieval Warm Period and an average value of 4.31 floods per decade over the four parts of the Little Ice Age can be determined, which latter value is more than ten times greater than the mean flood frequency experienced during the Medieval Warm Period.

Introducing their study of the subject, Stewart *et al*. (2011) note that "regional climate models project that future climate warming in Central Europe will bring more intense summer-autumn heavy precipitation and floods as the atmospheric concentration of water vapor increases and cyclones intensify," citing the studies of Arnell and Liu (2001), Christensen and Christensen (2003) and Kundzewicz *et al*. (2005). In an exercise designed to assess the reasonableness of these projections, Stewart *et al*. derived "a complete record of paleofloods, regional glacier length changes (and associated climate phases) and regional glacier advances and retreats (and associated climate transitions) … from the varved sediments of Lake Silvaplana (ca. 1450 BC-AD 420; Upper Engadine, Switzerland)," while indicating that "these records provide insight into the behavior of floods (i.e. frequency) under a wide range of climate conditions."

Based on their analysis, the five researchers report there was "an increase in the frequency of paleofloods during cool and/or wet climates and windows of cooler June-July-August temperatures" and that the frequency of flooding "was reduced during warm and/or dry climates." And reiterating the fact that "the findings of this study suggest that the frequency of extreme summer-autumn precipitation events (i.e. flood events) and the associated atmospheric pattern in the Eastern Swiss Alps was not enhanced during warmer (or drier) periods," Stewart *et al*. acknowledge that "evidence could not be found that summer-autumn floods would increase in the Eastern Swiss Alps in a warmer climate of the 21st century," in contrast to the projections of the regional climate models that have suggested otherwise.

Mudelsee *et al*. (2004) prefaced their work by writing "extreme river floods have had devastating effects in central Europe in recent years," citing as examples the Elbe flood of August 2002, which caused 36 deaths and inflicted damages totaling over 15 billion U.S. dollars, and the Oder flood of July 1997, which caused 114 deaths and inflicted approximately 5 billion dollars in damages. And they noted that concern had been expressed in this regard "in the Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change," wherein it was stated that "current anthropogenic changes in atmospheric composition will add to this risk."

Unconvinced about this contention, the four researchers reevaluated the quality of data and methods of reconstruction that had previously produced flood histories of the middle parts of the Elbe and Oder rivers back to AD 1021 and 1269, respectively; and in doing so, they found, for both the Elbe and Oder rivers, "no significant trends in summer flood risk in the twentieth century," but "significant downward trends in winter flood risk," which latter phenomenon—described by them as "a reduced winter flood risk during the instrumental period"—they specifically described as "a response to regional warming." Thus, their study provided no support whatsoever for the IPCC "concern" that CO_2-induced warming would add to the risk of river flooding in Europe. If anything, their findings suggested just the *opposite*.

Writing as background for their work, Buntgen *et al*. (2011) correctly indicate that instrumental station measurements, which systematically cover only the last 100-150 years, "hinder any proper assessment of the statistical likelihood of return period, duration and magnitude of climatic extremes," stating that "a palaeoclimatic perspective is therefore indispensable to place modern trends and events in a pre-industrial context (Battipaglia *et al*., 2010), to disentangle effects of human greenhouse gas emission from natural forcing and internal oscillation (Hegerl *et al*., 2011), and to constrain climate model simulations and feedbacks of the global carbon cycle back in time (Frank *et al*., 2010)." In an effort to satisfy these requirements and help facilitate the accomplishment of the associated goals, Buntgen *et al*. "introduce and analyze 11,873 annually resolved and absolutely dated ring width measurement series from living and historical fir (*Abies alba* Mill.) trees sampled across France, Switzerland, Germany and the Czech Republic, which continuously span the AD 962-2007 period," and which "allow Central European hydroclimatic springtime extremes of the industrial era to be placed against a 1,000 year-long backdrop of natural variations."

In the words of the nine researchers, their data revealed "a fairly uniform distribution of hydroclimatic extremes throughout the Medieval Climate Anomaly, Little Ice Age and Recent Global Warming." Such finding, as stated by the authors, "may question the common belief that frequency and severity of such events closely relates to climate mean states," which conclusion represents a rebuke of the claim that global warming will lead to more frequent and severe floods and droughts.

Lindstrom and Bergstrom (2004) analyzed runoff and flood data from more than 60 discharge stations scattered throughout Sweden, some of which provided information stretching as far back in time as the early to mid-1800s, when Sweden and the world were still experiencing the cold of the Little Ice Age. This analysis led them to discover that the last 20 years of the past century were indeed unusually wet, with a runoff anomaly of +8% compared with the century average. But they also found "the runoff in the 1920s was comparable to that of the two latest decades," and "the few observation series available from the 1800s show that the runoff was even higher than recently." In addition, they determined "flood peaks in old data [were] probably underestimated," which "makes it difficult to conclude that there has really been a significant increase in average flood levels." Also, they say "no increased frequency of floods with a return period of 10 years or more, could be determined."

With respect to the generality of their findings, Lindstrom and Bergstrom concluded that conditions in Sweden "are consistent with results reported from nearby countries: e.g. Forland *et al*. (2000), Bering Ovesen *et al*. (2000), Klavins *et al*. (2002) and Hyvarinen (2003)," and that, "in general, it has been difficult to show any convincing evidence of an increasing magnitude of floods (e.g. Roald, 1999) in the near region, as is the case in other parts of the world (e.g. Robson *et al*., 1998; Lins and Slack, 1999; Douglas *et al*., 2000; McCabe and Wolock, 2002; Zhang *et al*., 2001)."

In Asia, Davi *et al*. (2006) developed a reconstruction of streamflow that extended from 1637 to 1997, based on absolutely dated tree-ring-width chronologies from five sampling sites in west-central Mongolia, all of which sites were in or near the Selenge River basin, the largest river in Mongolia. Of the ten wettest five-year periods, only two occurred during the 20th century (1990-

1994 and 1917-1921, the second and eighth wettest of the ten extreme periods, respectively), once again indicative of a propensity for less flooding during the warmest portion of the record.

In a study of the Yangtze Delta, Zhang *et al*. (2007) developed flood and drought histories of the past thousand years "from local chronicles, old and very comprehensive encyclopedia, historic agricultural registers, and official weather reports," after which "continuous wavelet transform was applied to detect the periodicity and variability of the flood/drought series" and, finally, the results of the entire set of operations were compared with 1000-year temperature histories of northeastern Tibet and southern Tibet. This work revealed "colder mean temperature in the Tibetan Plateau usually resulted in higher probability of flood events in the Yangtze Delta region," and the authors say that "during AD 1400-1700 [the coldest portion of their record, corresponding to much of the Little Ice Age], the proxy indicators showing the annual temperature experienced larger variability (larger standard deviation), and this time interval exactly corresponds to the time when the higher and significant wavelet variance occurred." In contrast, they report that "during AD 1000-1400 [the warmest portion of their record, corresponding to much of the Medieval Warm Period], relatively stable climatic changes reconstructed from proxy indicators in Tibet correspond to lower wavelet variance of flood/drought series in the Yangtze Delta region."

In another study focusing on the Yangtze Delta, Zhang *et al*. (2009) utilized wavelet analysis on the decadal locust abundance data of Ma (1958) for the AD 950s-1950s, the decadal Yangtze Delta flood and drought frequency data of Jiang *et al*. (2005) for the AD 1000s-1950s, and the decadal mean temperature records of Yang *et al*. (2002) for the AD 950s-1950s, "to shed new light on the causal relationships between locust abundance, floods, droughts and temperature in ancient China." In doing so, the international team of Chinese, French, German and Norwegian researchers found that coolings of 160-170-year intervals dominated climatic variability in China over the past millennium, and that these cooling periods promoted locust plagues by enhancing temperature-associated drought/flood events. As a result, the six scientists say that "global warming might not only imply reduced locust plague[s], but also reduced risk of droughts and floods for entire China," noting that these findings "challenge the popular view that global warming necessarily accelerates natural and biological disasters such as drought/flood events and outbreaks of pest insects," as promulgated by the most recent report of the Intergovernmental Panel on Climate Change. Indeed, they say their results are an example of "benign effects of global warming on the regional risk of natural disasters."

Taken together, the studies referenced above clearly demonstrate a lack of evidence for the hypothesis that CO_2-induced global warming is increasing the frequency and magnitude of flood events. If anything, it suggests flooding tends to be reduced and less severe when the planet experienced warmer, as opposed to colder, temperatures.

3.1.3. Other Factors Driving Observed Trends

Although the prior two subsections have convincingly demonstrated that the hypothesis that rising CO_2 is causing an increase in floods is false, the present section provides additional evidence negating such claims. It also demonstrates the presence and importance of other natural and anthropogenic factors that influence flood records. These influences must be studied and factored out before any portion of a flooding trend could be attributed to CO_2-induced global warming.

The first of these examples comes from a study testing for long-term changes in flood magnitudes and frequencies conducted in the Mississippi River system by Pinter *et al*. (2008), who "constructed a hydrologic database consisting of data from 26 rated stations (with both stage and discharge measurements) and 40 stage-only stations." To help "quantify changes in flood levels at each station in response to construction of wing dikes, bendway weirs, meander cutoffs, navigational dams, bridges, and other modifications," the researchers put together a geospatial database consisting of "the locations, emplacement dates, and physical characteristics of over 15,000 structural features constructed along the studied rivers over the past 100-150 years." And as a result of these operations, Pinter *et al*. say that "significant climate- and/or land use-driven increases in flow were detected," but they indicate that "the largest and most pervasive contributors to increased flooding on the Mississippi River system were wing dikes and related navigational structures, followed by progressive levee construction."

In discussing the implications of their findings, Pinter *et al*. write that "the navigable rivers of the Mississippi system have been intensively engineered, and some of these modifications are associated with large decreases in the rivers' capacity to convey flood flows." Given such findings, it would appear that man may indeed have been responsible for the majority of the enhanced flooding of the rivers of the Mississippi system over the past century or so, but not in the way suggested by the IPCC. The question that needs addressing by the region's inhabitants, therefore, has nothing to do with CO_2, but everything to do with how to "balance the local benefits of river engineering against the potential for large-scale flood magnification."

Similar findings have been reported for the Upper Midwest (consisting of North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, Missouri, Wisconsin and Illinois) by Villarini *et al*. (2011), who "analyzed the annual maximum instantaneous flood peak distributions for 196 U.S. Geological Survey streamflow stations with a record of at least 75 years over the Midwest U.S." According to the four U.S. researchers who conducted this study, in the vast majority of cases where streamflow changes were observed, they were "associated with change-points (both in mean and variance) rather than monotonic trends," and they indicated that "these non-stationarities are often associated with anthropogenic effects." But rather than associate the increases with anthropogenic CO_2 emissions, they cite such things as "changes in land use/land cover, changes in agricultural practice, and construction of dams and reservoirs" as the primary cause(s). As a result, and, as they note, "in agreement with previous studies (Olsen *et al*., 1999; Villarini *et al*., 2009)," they conclude that "there is little indication that anthropogenic climate change has significantly affected the flood frequency distribution for the Midwest U.S." And as they make doubly clear in the abstract of their paper, they say that "trend analyses do not suggest an increase in the flood peak distribution due to anthropogenic climate change."

Writing as background for their work, Barredo *et al*. (2012) say that "economic impacts from flood disasters have been increasing over recent decades," but they add that "despite the fact that the underlying causes of such increase are often attributed to a changing climate, scientific evidence points to increasing exposure and vulnerability as the main factors responsible for the increase in losses," citing the studies of Pielke and Landsea (1998), Crompton and McAneney

(2008), Pielke *et al*. (2008), Barredo (2009, 2010), and Neumayer and Barthel (2011). Ever curious, however—and possibly looking for exceptions—Barredo *et al*. set out to examine “the time history of insured losses from floods in Spain between 1971 and 2008,” striving to see “whether any discernible residual signal remains after adjusting the data for the increase in the number and value of insured assets over this period of time.”

The “most salient feature” of Barredo *et al*.’s findings, as they describe it, was “the absence of a significant positive trend in the adjusted insured flood losses in Spain,” which suggests, in their words, that “the increasing trend in the original losses is explained by socio-economic factors, such as the increases in exposed insured properties, value of exposed assets and insurance penetration.” And they add that “there is no residual signal that remains after adjusting for these factors,” so that “the analysis rules out a discernible influence of anthropogenic climate change on insured losses,” which they say “is consistent with the lack of a positive trend in hydrologic floods in Spain in the last 40 years.”

In the introduction to their study of the hydrology of German rivers, Bormann *et al*. (2011) write that “following several severe floods in Germany during the past two decades, [the] mass media as well as scientists have debated the relative contributions of climate and/or anthropogenic processes to those floods.” Driven by a desire to help resolve this climate-change impact debate, the three researchers utilized long time-series of stage and discharge data obtained from 78 river gauges in Germany, searching for trends in flood frequency, peak discharge, peak stage and stage-discharge relationships, where all variables investigated had to have a temporal history on the order of at least half a century.

In doing so, the three researchers first established the nature of Germany’s temperature history, noting that Schonwiese (1999) identified a homogenous positive trend of 0.5-1.0°C over the course of the 20th century, which was subsequently confirmed by Gerstengarbe and Werner (2008) and Bormann (2010). Then, in terms of land use change between 1951 and 1989, they report that “agricultural area in Germany decreased from 57.8% to 53.7%, while forested areas remained almost constant.” During this same time period, they report “impervious areas increased sharply from 7.4% to 12.3%,” and they say “this trend has continued since 1989,” with impervious areas further increasing from 11.2% to 13.1%, forest areas increasing from 29.3% to 30.1%, and agricultural area decreasing from 54.7% to 52.5%. And as a consequence of the net increase in impervious surfaces, they say “runoff generation can be expected to increase and infiltration and groundwater recharge decrease,” which would be expected to lead to increases in river flow and a potential for more frequent and extreme floods. However, they report “most stations analyzed on the German rivers did not show statistically significant trends in any of the metrics analyzed.”

In light of these several observations—plus the fact that “most decadal-scale climate-change impacts on flooding (Petrow and Merz, 2009) are small compared to historic peaks in flood occurrence (Mudelsee *et al*., 2006)”—Bormann *et al*. concluded their report by stating that these significant facts “should be emphasized in the recent discussion on the effect of climate change on flooding.” And if this is done, there is no other conclusion to be drawn but that the warming experienced in Germany over the past century has not led to unprecedented flooding throughout the country. In fact, it has not led to any increase in flooding.

The findings presented above clearly illustrate the *fact* that many other factors, natural and anthropogenic and unrelated to CO_2-induced global warming, can influence records of flooding. A proper accounting of their influence must be conducted before assessing a potential role from rising CO_2.

3.2. Drought

Like *floods*, many researchers have investigated how *droughts* have responded to the global warming of the past several decades. This section highlights the results of numerous empirical data analyses that shed light on the climate-alarmist claim that CO_2-induced global warming is leading to more frequent and intensified drought events around the globe. These studies clearly indicate there is nothing unusual about drought events of the modern era. The large droughts that have occurred recently have many historic analogs that occurred during times when the atmosphere's CO_2 concentration was *much* lower than it is currently. Taken together, these materials suggest that the ongoing rise in atmospheric CO_2 is having no measurable impact on modern drought events.

3.2.1. Trends of the Past Century

The first step in evaluating claims that rising CO_2 is causing more frequent and severe droughts begins with a rather simple analysis of drought events over the past few decades, during which time the bulk of Earth's anthropogenic-produced CO_2 accumulated in the atmosphere. If the observational data show no concurrent trends in drought events, or if they are shown to decline over this period, the hypothesis that rising CO_2 is increasing the frequency and/or magnitude of these events can be falsified, as such findings contradict the hypothesis. This section thus examines the results of several scientific studies that have performed this initial phase of drought uniqueness evaluation.

Andreadis and Lettenmaier (2006) examined 20th-century trends in soil moisture, runoff and drought over the conterminous United States with a hydro-climatological model forced by real-world measurements of precipitation, air temperature and wind speed over the period 1915-2003. This work revealed, in their words, that "droughts have, for the most part, become shorter, less frequent, less severe, and cover a smaller portion of the country over the last century," in a rebuke of model-based claims concerning global warming and its effects on drought.

Quiring and Papakyriakou (2005) used an agricultural drought index (Palmer's Z-index) to characterize the frequency, severity and spatial extent of June-July moisture anomalies for 43 crop districts from the agricultural region of the Canadian prairies over the period 1920-1999. This work revealed that for the 80-year period of their study, the single most severe June-July drought on the Canadian prairies occurred in 1961, and that the next most severe droughts, in descending order of severity, occurred in 1988, 1936, 1929 and 1937, for little net overall trend. At the same time, however, they say there was an upward trend in mean June-July moisture conditions. In addition, they note that "reconstructed July moisture conditions for the Canadian prairies demonstrate that droughts during the 18th and 19th centuries were more persistent than those of the 20th century (Sauchyn and Skinner, 2001)."

Focusing on Asia, Cluis and Laberge (2001) analyzed streamflow records stored in the databank of the Global Runoff Data Center at the Federal Institute of Hydrology in Koblenz (Germany) to see if there were any changes in Asian river runoff of the type predicted by climate alarmists to lead to more frequent and more severe drought. More specifically, their study was based on the streamflow histories of 78 rivers said to be "geographically distributed throughout the whole Asia-Pacific region." The mean start and end dates of these series were 1936 ± 5 years and 1988 ± 1 year, respectively, representing an approximate half-century time span. Results of their analysis indicate that in the case of the annual minimum discharges of these rivers, which are the ones associated with drought, 53% of them were unchanged over the period of the study; and where there *were* trends, 62% of them were upward, indicative of a growing likelihood of both less frequent and less severe drought.

Noting "the media often reflect the view that recent severe drought events are signs that the climate has in fact already changed owing to human impacts," Hisdal *et al*. (2001) examined pertinent data from many places in Europe. Specifically, they performed a series of statistical analyses on more than 600 daily streamflow records from the European Water Archive to examine trends in the severity, duration and frequency of drought over the four time periods 1962-1990, 1962-1995, 1930-1995, and 1911-1995. This work revealed, in their words, that "despite several reports on recent droughts in Europe, there is no clear indication that streamflow drought conditions in Europe have generally become more severe or frequent in the time periods studied." Quite to the contrary, they found that "overall, the number of negative significant trends pointing towards decreasing drought deficit volumes or fewer drought events exceeded the number of positive significant trends (increasing drought deficit volumes or more drought events)."

In another paper, van der Schrier *et al*. (2006) constructed monthly maps of the Self-Calibrating Palmer Drought Severity Index (SC-PDSI, a variant put forward by Wells *et al*. (2004) of the more common PDSI) for the period 1901-2002 for Europe (35°N-70°N, 10°W-60°E), which index, in their words, "improves upon the PDSI by maintaining consistent behavior of the index over diverse climatological regions," which "makes spatial comparisons of SC-PDSI values on continental scales more meaningful." In doing so, they found that "over the region as a whole, the mid-1940s to early 1950s stand out as a persistent and exceptionally dry period, whereas the mid-1910s and late 1970s to early 1980s were very wet." Over the entire study period, however, they found that trends in the continent's summer moisture availability "fail to be statistically significant, both in terms of spatial means of the drought index and in the area affected by drought." In addition, they say that "evidence for widespread and unusual drying in European regions over the last few decades [as suggested by the work of Briffa *et al*. (1994) and Dai *et al*. (2004)] is not supported by the current work," in that "values for the total percentage area subject to extreme moisture conditions in the years 1996-99 returned to normal levels at ~2% from a maximum of nearly 10% in 1990." And in further support of their findings, the four researchers note that "the absence of a trend toward summer desiccation has recently also been observed in soil moisture records in the Ukraine (Robock *et al*., 2005) and supports conclusions in the current study."

Working in the Southern Hemisphere, Minetti *et al*. (2010) evaluated the annual occurrence of droughts and their persistence in what they describe as "an attempt to determine any aspects of the impact of global warming." This was accomplished by examining a regional inventory of monthly droughts for the portion of South America located south of approximately 22°S latitude—which was divided into six sections (the central region of Chile plus five sections making up most of Argentina). The results of this effort indicated, in the words of the authors, "the presence of long favorable tendencies [1901-2000] regarding precipitations or the inverse of droughts occurrence are confirmed for the eastern Andes Mountains in Argentina with its five sub-regions (Northwest Argentina, Northeast Argentina, Humid Pampa, West-Centre Provinces and Patagonia) and the inverse over the central region of Chile." From the middle of 2003 to 2009, however, they report "an upward trend in the occurrence of droughts with a slight moderation over the year 2006." However, they additionally note that the driest single year periods were 1910-11, 1915-16, 1916-17, 1924-25 and 1933-34, suggesting that 20th-century global warming has not promoted an abnormal increase in droughts over the southern third of South America.

Svensson *et al*. (2005) examined 20th-century river flow data for a group of 21 stations distributed around the globe. Individual record lengths of the 21 stations varied from 44 to 100 years, with an average of 68 years; and the three researchers' analyses of the data consisted of computing trends in both high flows and low flows using Mann-Kendall and linear regression methods. This work revealed, in the case of *low*-flows, nearly *all* stations showed *increasing* trends, approximately half of which were significant at the 90% level, indicative of a general trend of *decreasing* drought throughout the world.

Narisma *et al*. (2007) analyzed "global historical rainfall observations to detect regions that have undergone large, sudden decreases in rainfall [that] are statistically significant at the 99% level, are persistent for at least ten years, and ... have magnitudes that are [mostly] 10% lower than the climatological normal (1901-2000 rainfall average)." And working with the gridded high-resolution (0.5 x 0.5 degrees of latitude and longitude) global precipitation data set of Mitchell *et al*. (2004), which covers the period 1901-2000, they identified 30 drought episodes throughout the world that satisfied these stringent criteria during the 20th century, among which were the sudden and prolonged Sahel drought of Africa in the late 1960s, the United States Dust Bowl of the 1930s and Southwest drought of the 1950s (which also affected parts of Mexico), the strong and persistent droughts that occurred in northeast China in the 1920s, in Kazakhstan and regions of the former Soviet Union in the late 1930s, in southeast Australia in the late 1930s, and in southern Africa and eastern Europe in the 1980s, as well as the World War II droughts of 1937-1945 and the droughts that occurred over large regions of East India and Bangladesh in the 1950s.

With respect to the *temporal distribution* of the 30 severe and persistent droughts identified by Narisma *et al*., seven of them occurred during the first two decades of the 20th century (1901-1920), seven occurred during the next two decades (1921-1940), eight during the middle two decades of the century (1941-1960), but only five during the next two decades (1961-1980), and a mere *three* during the final two decades of the century (1981-2000), which is not at all what one would have expected if the model-based thesis propounded by climate alarmists is correct.

In commenting on their findings, the authors note that the 30 major droughts they identified were "mostly located in semi-arid and arid regions" that "are naturally prone to large fluctuations." Thus, the 30 major droughts of the 20th century were likely *natural* in all respects; and, hence, they are "indicative of what could also happen in the future," as Narisma *et al*. state in their concluding paragraph. And sooner or later they *will* happen, but independently of the air's CO_2 concentration or the globe's temperature, just as they have done in the past.

In one final global-scale analysis, Sheffield *et al*. (2009) used "observation-driven simulations of global terrestrial hydrology and a cluster algorithm that searches for spatially connected regions of soil moisture," to identify "296 large scale drought events (greater than 500,000 km^2 and longer than 3 months) globally for 1950-2000." And in doing so, they found that "the mid-1950s showed the highest drought activity and the mid-1970s to mid-1980s the lowest activity."

The results of the several studies discussed above all fail to support the hypothesis that CO_2-induced global warming increased the frequency and severity of drought over the past few decades. The next section reviews work that was conducted over even *longer* time periods; and it also reveals no systematic change in drought in response to what climate alarmists refer to as the *unprecedented warming* of the late 20th and early 21st centuries.

3.2.2. Natural Variability Seen from Long-term, Centennial-scale Studies

Beyond short-term analyses of only a few decades, a number of studies have examined droughts over centennial to millennial time scales. These studies, which comprise those reviewed in this section, allow the comparison of drought events that occurred prior to the modern buildup of anthropogenic CO_2 in the air with those that occurred after it. These types of analyses reveal great detail about the breadth and depth of natural variability and are of great value in investigating the potential influence of rising CO_2 on droughts.

Starting in the central United States, Tian *et al*. (2006) derived a 31-century high-resolution $\delta^{18}O$ record of aridity, which they obtained from sediments extracted from Steel Lake (46°58'N, 94°41'W) in north-central Minnesota, USA. Among their findings, they note that "the region was relatively dry during the Medieval Climate Anomaly (~1400-1100 AD) and relatively wet during the Little Ice Age (~1850-1500 AD), but that the moisture regime varied greatly within each of these two periods." Their most striking finding of all, however, was the fact that "drought variability was anomalously low during the 20th century." In fact, it was so depressed, as they describe it, that "~90% of the variability values during the last 3100 years were greater than the 20th-century average."

Stambaugh *et al*. (2011) "used a new long tree-ring chronology developed from the central U.S. to reconstruct annual drought and characterize past drought duration, frequency, and cycles in the agriculturally-important U.S. Corn Belt region during the last millennium," which chronology they calibrated and verified against monthly values of the instrumental Palmer Hydrologic Drought Index during the summer season of June, July and August. In doing so, the six scientists report that "20th century droughts, including the Dust Bowl, were relatively unremarkable when compared to drought durations prior to the instrumental record." They note, for example, that the 19th century was the driest of the past millennium, with major drought periods occurring from about 1816 to 1844 and 1849 to 1880, during what they describe as the transition out of the Little Ice Age. Prior to that, there had been 45 years of drought in the latter part of the 17th century that were coincident with the Maunder Minimum of solar activity, which is associated with the coldest period of the current interglacial. And going back further in time, there was an approximately 35-year drought in the mid- to late-15th century during "a period of decreased radiative forcing and northern hemisphere temperatures."

Eclipsing them all, however, Stambaugh *et al*. write that "the approximately 61-year drought in the late 12th century (ca. AD 1148-1208) appears to be the most significant drought of the entire reconstruction," noting that it "corresponds to the single greatest megadrought in North America during the last 2000 years (Cook *et al*., 2007), as well as "unmatched persistent low flows in western U.S. river basins (Meko *et al*., 2007)." And this drought, as they describe it, occurred during the middle of the Medieval Warm Period—"an interval of warmer temperatures between approximately AD 800-1300 characterized by greater drought duration and frequency in the Northern Great Plains compared to more modern times." Thus, it is abundantly clear from Stambaugh *et al*.'s findings that there is nothing unusual, unnatural or unprecedented about *any* 20th or 21st century droughts that may have occurred throughout the agricultural heartland of the United States. It is also clear that the much greater droughts of the past millennium occurred during periods of both relative cold *and* relative warmth, as well as the transitions between them.

It is clear from the two prior studies that there is nothing unusual, unnatural, or unprecedented about recent droughts in the central United States. Droughts of greater duration and intensity have occurred numerous times in the past, eclipsing anything that has been observed in the modern record. Claims of increasing future drought as a result of global warming are therefore not supported by real-world data, as modern global warming, if anything, has tended to lessen drought conditions throughout the central third of the United States.

Moving to the east, Quiring (2004) introduced his study of the subject by describing the drought of 2001-2002, which by June of the latter year had produced anomalously dry conditions along most of the east coast of the country, including severe drought conditions from New Jersey to northern Florida that forced 13 states to ration water. Shortly after the drought began to subside in October of 2002, however, moist conditions returned and persisted for about a year, producing the wettest growing-season of the instrumental record. These observations, in Quiring's words, "raise some interesting questions," including the one considered here—"are moisture conditions in this region becoming more variable?"

Using an 800-year tree-ring-based reconstruction of the Palmer Hydrological Drought Index to address this question, Quiring documented the frequency, severity and duration of growing-season moisture anomalies in the southern mid-Atlantic region of the United States. Among other things, this work revealed, in Quiring's words, that "conditions during the 18th century were much wetter than they are today, and the droughts that occurred during the 16th century tended to be both longer and more severe." He therefore concluded that "the recent growing-season moisture anomalies that occurred during 2002 and 2003 can only be considered rare events if they are evaluated with respect to the relatively short instrumental record (1895-2003)," for when compared to the 800-year reconstructed record, he notes that "neither of these events is particularly unusual." In addition, Quiring reports that "although climate models predict decreases in summer precipitation and significant increases in the frequency and duration of extreme droughts, the data indicate that growing-season moisture conditions during the 20th century (and even the last 19 years) appear to be near normal (well within the range of natural climate variability) when compared to the 800-year record."

Across the continent, Gedalof *et al*. (2004) used a network of 32 drought-sensitive tree-ring chronologies to reconstruct mean water-year flow on the Columbia River at The Dales in Oregon since 1750. This study of the second largest drainage basin in the United States is stated by them to have been done "for the purpose of assessing the representativeness of recent observations, especially with respect to low frequency changes and extreme events." When finished, it revealed, in their words, that "persistent low flows during the 1840s were probably the most severe of the past 250 years," and that "the drought of the 1930s is probably the second most severe." More recent droughts, in the words of the researchers, "were not exceptional in the context of the last 250 years and were of shorter duration than many past events." In fact, they say that "the period from 1950 to 1987 is anomalous in the context of this record for having no notable multiyear drought events," demonstrating the fact that Pacific Northwest droughts have not become more severe or long-lasting as temperatures have risen over the course of the 20th century.

MacDonald and Tingstad (2007) examined instrumental climate records to outline historical spatiotemporal patterns of precipitation variability in the Uinta Mountains, after which they "used tree-ring width chronologies from *Pinus edulis* Engelm. (two-needle pinyon pine) trees growing near the northern and southern flanks of the mountains to produce an ~600-year reconstruction (AD 1405-2001) of Palmer Drought Severity Index [PDSI] for Utah Climate Division 5," which they say "allows for the placement of 20th century droughts within the longer context of natural drought variability and also allows for the detection of long-term trends in drought." The researchers report that "in the context of prolonged severe droughts," the 20th century "has been relatively moist compared to preceding centuries," and they say their PDSI reconstruction and the Uinta Basin precipitation reconstruction indicate "the early to mid-17th century in particular, and portions of the 18th and 19th centuries, experienced prolonged (>10 years) dry conditions that would be unusually severe by 20th century standards," noting that "the most striking example of widespread extended drought occurred during a ~45-year period between 1625 and 1670 when PDSI only rarely rose above negative values."

Allen *et al*. (2013) introduce their study by noting climate *models* "predict the western U.S. will experience reduced snowpack, increased temperatures, and more severe and longer duration droughts," citing Barnett *et al*. (2004), Cook *et al*. (2004) and Barnett and Pierce (2009)," and they add the models predict the warming will "intensify the effects of droughts and their economic impact," citing Rauscher *et al*. (2008). In a test of such claims, Allen *et al*. "created six new tree-ring chronologies in northern Utah, which were used with pre-existing chronologies from Utah and western Wyoming to reconstruct mean annual flow for the Logan River, the largest tributary of the regionally important Bear River," which efforts resulted in what they say is "the first extended record of streamflow in northern Utah," covering the 400-year period of AD 1605-2005.

According to the six scientists, their work reveals "the Logan River has experienced highly variable streamflow over the last four centuries," adding this variability "is only partly apparent when considering only the instrumental record." And in this regard they further note "the instrumental record does not capture the full range of natural variability," as they say has been found to be the case "in studies in surrounding basins and across the western U.S.," citing Graumlich *et al*. (2003), Woodhouse *et al*. (2006), Timilsena *et al*. (2007), Watson *et al*. (2009) Barnett *et al*. (2010) and Wise (2001). More specifically, they indicate their reconstructions of Logan River flow suggest "overall flows were more variable at times preceding the instrumental period," and "it is likely that past droughts and wet periods [were] more extreme than the models indicate, thereby implying the possibility that water supplies may have been more volatile in the past." It would therefore appear that, rather than causing droughts and floods to become both more frequent and severe than they have been in the past, as climate models are prone to predict for a CO_2-warmed world (such as is claimed we now reside in by many of the world's climate alarmists), in the case of northern Utah and western Wyoming—and possibly much more of the intermountain U.S. west—just the *opposite* appears to have been the case when lengthy real-world data sets have been obtained and analyzed.

Introducing their study of "perfect drought" in Southern California, MacDonald *et al*. (2008) define the term as "a prolonged drought that affects southern California, the Sacramento River basin and the upper Colorado River basin simultaneously." They note the instrumental record indicates the occurrence of such droughts throughout the past century, but they "generally persist for less than five years." That they have occurred at all, however, suggests the possibility of even longer perfect droughts, which could well prove catastrophic for the region. Thus, the three researchers explored the likelihood of such droughts occurring in the future, based on dendrochronological reconstructions of the winter Palmer Drought Severity Index (PDSI) in southern California over the past thousand years, plus the concomitant annual discharges of the Sacramento and Colorado Rivers, under the logical assumption that what has occurred before may well occur again. And in doing so, MacDonald *et al*. found that "prolonged perfect droughts (~30-60 years), which produced arid conditions in all three regions simultaneously, developed in the mid-11th century and the mid-12th century during the period of the so-called 'Medieval Climate Anomaly'," which is also widely known as the Medieval Warm Period, leading them to conclude that "prolonged perfect droughts due to natural or anthropogenic changes in radiative forcing, are a clear possibility for the near future."

In another study, Woodhouse and Lukas (2006) developed "a network of 14 annual streamflow reconstructions, 300-600 years long, for gages in the Upper Colorado and South Platte River basins in Colorado generated from new and existing tree-ring chronologies." And in the words of the two researchers, their reconstructions indicate that "the 20^{th}-century gage record does not fully represent the range of streamflow characteristics seen in the prior two to five centuries." Of greatest significance, in this regard, was the fact that "multi-year drought events more severe than the 1950s drought have occurred," and that "the greatest frequency of extreme low flow events occurred in the 19th century," with a "clustering of extreme event years in the 1840s and 1850s."

Covering the whole of the western United States was Woodhouse (2004), who reported what is known about natural hydroclimatic variability throughout the entire region via descriptions of several major droughts that occurred there over the past three millennia, all but the last century of which had atmospheric CO_2 concentrations that never varied by more than about 10 ppm from a mean value of 280 ppm.

For comparative purposes, Woodhouse began by noting that “the most extensive U.S. droughts in the 20th century were the 1930s Dust Bowl and the 1950s droughts.” The first of these droughts lasted “most of the decade of the 1930s” and “occurred in several waves,” while the latter “also occurred in several waves over the years 1951-1956.” Far more severe than either of these two droughts, however, was the 16th-Century Megadrought, which lasted from 1580 to 1600 and included northwestern Mexico in addition to the southwestern United States and the western Great Plains. Then there was The Great Drought, which spanned the last quarter of the 13th century and was actually the last in a series of three 13th-century droughts, the first of which may have been even more severe than the last. In addition, Woodhouse noted there was a period of remarkably sustained drought in the second half of the 12th century.

It is evident from these observations, according to Woodhouse, that “the 20^{th}-century climate record contains only a subset of the range of natural climate variability in centuries-long and longer paleoclimatic records.” It is also obvious that this subset, as it pertains to water shortage, does not even begin to approach the level of drought severity and duration experienced in prior centuries and millennia, which fact was confirmed in a separate paper published by Woodhouse and four collaborators a few years later (Woodhouse *et al*., 2010). This being the case, it is also clear it would take a drought much more extreme than the most extreme droughts of the 20th century to propel the western United States and adjacent portions of Canada and Mexico into a truly unprecedented state of dryness.

A similar assessment was reached by Cook *et al*. (2010), who prefaced their analysis by writing that “IPCC Assessment Report 4 model projections suggest that the subtropical dry zones of the world will both dry and expand poleward in the future due to greenhouse warming,” and that “the US southwest is particularly vulnerable in this regard and model projections indicate a progressive drying there out to the end of the 21st century.” They then state “the USA has been in a state of drought over much of the West for about 10 years now,” and “while severe, this turn of the century drought has not yet clearly exceeded the severity of two exceptional droughts in the 20th century,” so “while the coincidence between the turn of the century drought and projected drying in the Southwest is cause for concern, it is premature to claim that the model projections are correct.”

This fact is understood when the “turn of the century drought” is compared with the two “exceptional droughts” that preceded it by a few decades. Based on gridded instrumental Palmer Drought Severity indices for tree ring reconstruction that extend back to 1900, for example, Cook *et al*. (2010) calculated that the turn-of-the-century drought had its greatest Drought Area Index value of 59% in the year 2002, while the Great Plains/Southwest drought covered 62% of the US in its peak year of 1954, and the Dust Bowl drought covered 77% of the US in 1934. In terms of drought duration, on the other hand, things are not quite as clear. Stahle *et al*. (2007) estimated that the first two droughts lasted for 12 and 14 years, respectively; Seager *et al*. (2005)

estimated them to have lasted for 8 and 10 years; and Andreadis *et al*. (2005) estimated them to have lasted for 7 and 8 years, yielding means of 9 and 11 years for the two exceptional droughts, which durations are to be compared to 10 or so years for the turn-of-the-century drought, which again makes the latter drought not unprecedented compared to those that occurred earlier in the 20th century.

Real clarity, however, comes when the turn-of-the-century drought is compared to droughts of the prior millennium. Cook *et al*. (2010) write that "perhaps the most famous example is the 'Great Drouth' (sic) of AD 1276-1299 described by A.E. Douglass (1929, 1935)." Yet this 24-year drought was eclipsed by the 38-year drought that was found by Weakley (1965) to have occurred in Nebraska from AD 1276 to 1313, which the authors say "may have been a more prolonged northerly extension of the 'Great Drouth'." But even these multi-decade droughts truly pale in comparison to the "two extraordinary droughts discovered by Stine (1994) in California that lasted more than two centuries before AD 1112 and more than 140 years before AD 1350." And each of these megadroughts, as Cook *et al*. (2010) describe them, occurred, in their words, "in the so-called Medieval Warm Period." And they add that "all of this happened *prior to the strong greenhouse gas warming that began with the Industrial Revolution*."

Given that the above-referenced medieval megadroughts "occurred without any need for enhanced radiative forcing due to anthropogenic greenhouse gas forcing"—because, of course, there was none at that time—Cook *et al*. (2010) rightfully concluded "there is no guarantee that the response of the climate system to greenhouse gas forcing will result in megadroughts of the kind experienced by North America in the past." And if proponents of the CO_2-induced global warming hypothesis refuse to acknowledge this possibility and continue to claim that global warming will most assuredly trigger the occurrence of medieval-like megadroughts, they will also have to acknowledge that the Medieval Warm Period of a thousand years ago had to have been much warmer than the Current Warm Period has been to date. But this acknowledgement destroys yet another of their claims, i.e., that the Earth is currently warmer than it has been for one (Mann *et al*., 1999) to two (Mann and Jones, 2003) millennia.

Moving up to Canada, St. George and Nielsen (2002) used "a ringwidth chronology developed from living, historical and subfossil bur oak in the Red River basin to reconstruct annual precipitation in southern Manitoba since AD 1409." According to the authors, "prior to the 20th century, southern Manitoba's climate was more extreme and variable, with prolonged intervals that were wetter and drier than any time following permanent Euro-Canadian settlement." Thus, 20th-century warming, if anything, led to more stable climatic conditions with fewer hydrologic extremes (floods and droughts) than was typical of prior Little Ice Age conditions. Consequently, St. George and Nielsen concluded that "climatic case studies in regional drought and flood planning based exclusively on experience during the 20th century may dramatically underestimate true worst-case scenarios."

Also working in Canada, Wolfe *et al*. (2005) conducted a multi-proxy hydro-ecological analysis of Spruce Island Lake in the northern Peace sector of the Peace-Athabasca Delta in northern Alberta. Their research revealed that hydro-ecological conditions in that region varied substantially over the past 300 years, especially in terms of multi-decadal dry and wet periods. More specifically, they found (1) recent drying in the region was not the product of Peace River flow regulation that began in 1968, but rather the product of an extended drying period that was initiated in the early to mid-1900s, (2) the multi-proxy hydro-ecological variables they analyzed were well correlated with other reconstructed records of natural climate variability, and (3) hydro-ecological conditions after 1968 have remained well within the broad range of natural variability observed over the past 300 years, with the earlier portion of the record actually depicting "markedly wetter and drier conditions compared to recent decades."

At the Pacific coast of North America (Heal Lake near the city of Victoria on Canada's Vancouver Island), Zhang and Hebda (2005) conducted dendroclimatological analyses of 121 well-preserved subfossil logs discovered at the bottom of the lake plus 29 Douglas-fir trees growing nearby that led to the development of an ~4,000-year chronology exhibiting sensitivity to spring precipitation. And in doing so, they found that "the magnitude and duration of climatic variability during the past 4,000 years are not well represented by the variation in the brief modern period." As an example of this fact, they note that spring droughts represented by ring-width departures exceeding two standard deviations below the mean in at least five consecutive years occurred in the late AD 1840s and mid-1460s, as well as the mid-1860s BC, and were more severe than any drought of the 20th century. In addition, the most persistent drought occurred during the 120-year period between about AD 1440 and 1560. Other severe droughts of multi-decadal duration occurred in the mid AD 760s-800s, the 540s-560s, the 150s-late-190s and around 800 BC. Wavelet analyses of the tree-ring chronology also revealed a host of natural oscillations on timescales of years to centuries, demonstrating that the 20th century was in no way unusual in this regard, as there were many times throughout the prior 4,000 years when it was both wetter and drier than it was during the last century of the past millennium.

Sauchyn *et al*. (2011), in their study of the subject, wrote that "a growing demand for the surface water resources of the Canadian Prairie Provinces has resulted in increasing vulnerability to hydrological drought," citing the studies of Schindler and Donahue (2006) and Wheaton *et al*. (2008); and they further note, in this regard, that "a shift in the amount and timing of streamflow represents the most serious risk from recent and projected climate warming in western Canada (Sauchyn *et al*., 2001)," adding that "the Saskatchewan River Basin is among Canada's most vulnerable watersheds, in terms of projected climate changes and impacts, and the sensitivity of natural systems and economic activities to Canada's most variable hydroclimate." Therefore, they felt it important to know the characteristics of past streamflow variability in order to better prepare for future droughts, as well as to determine if extreme droughts that may occur in the future might be due to CO_2-induced global warming or if they are within the range of natural variability experienced in the past, when the air's CO_2 concentration was both much lower and less variable than it is currently. And so the question arises: Is a mere century of real-world data sufficient for these purposes?

In a study designed to explore this important question by determining if streamflow variability recorded by the streamflow gauge at Edmonton, Alberta (Canada) over the past century (since 1912) is representative of the range of variability experienced there over the past millennium, Sauchyn *et al*. (2011) developed a 945-year reconstruction of the annual flow of the Northern Saskatchewan River based on tree-rings collected from seven different sites within the runoff-generating upper basin of the river (see Figure 4).

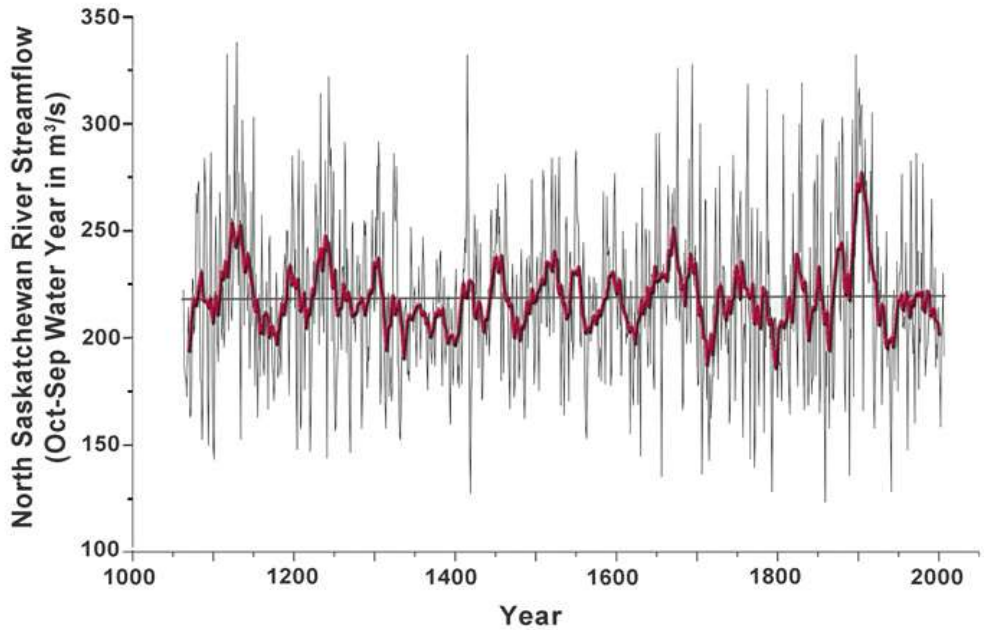

***Figure 4**. North Saskatchewan River reconstructed water year (October to September) flow for the period 1063-2006. Adapted from Sauchyn et al. 2011.*

Clearly, the Edmonton stream-gauge record does not "represent the full extent of inter-annual to multi-decadal variability in the tree-ring data," for as noted by Sauchyn *et al*. (2011) "there are periods of low flow in the pre-instrumental record that are longer and more severe than those recorded by the gauge" and which "pre-date Euro-Canadian settlement of the region." Two of these extreme events were approximate 30-year droughts, one occurring in the early 1700s and another during the mid-1100s, while one of the two most prominent mega-droughts lasted for most of the 14th century, while the other occurred in the latter part of the 15th century.

Sauchyn *et al*. thus go on to state "there is less certainty and stationarity in western [Canadian] water supplies than implied by the instrumental record," which they say is "the conventional basis for water resource management and planning" of the region. Likewise, it is clear that their streamflow reconstruction provides a whole new-and-improved basis for determining the "uniqueness" of whatever future droughts might occur throughout the region, making it much more difficult to claim that such droughts were caused by anthropogenic CO_2 emissions, since there was far less CO_2 in Earth's atmosphere prior to the 1912 start-date of the region's prior streamflow history, when several *way* more serious droughts than those of the past century are now known to have occurred.

Still in North America, but working down in Mexico, Diaz *et al*. (2002) constructed a history of winter-spring (November-April) precipitation—which accounts for one-third of the yearly total— for the state of Chihuahua for the period 1647-1992, based on earlywood width chronologies of over 300 Douglas fir trees growing at four locations along the western and southern borders of Chihuahua and at two locations in the United States just above Chihuahua's northeast border. And on the basis of these reconstructions, they note that "three of the 5 worst winter-spring drought years in the past three-and-a-half centuries are estimated to have occurred during the 20th century." Although this observation tends to make the 20th century look highly anomalous in this regard, it is not; for two of those three worst drought years occurred during a period of average to slightly-above-average precipitation.

Diaz *et al*. also note that "the longest drought indicated by the smoothed reconstruction lasted 17 years (1948-1964)," which is again indicative of abnormally dry conditions during the 20th century. However, for several of the 17 years of that below-normal-precipitation interval, precipitation values were only slightly below normal. For all practical purposes, therefore, there were four very similar dry periods interspersed throughout the preceding two and a half centuries: one in the late 1850s and early 1860s, one in the late 1790s and early 1800s, one in the late 1720s and early 1730s, and one in the late 1660s and early 1670s.

With respect to the 20th century alone, there was also a long period of high winter-spring precipitation that stretched from 1905 to 1932; and following the major drought of the 1950s, precipitation remained at or just slightly above normal for the remainder of the record. Finally, with respect to the entire 346 years, there was no long-term trend in the data, nor was there evidence of any sustained departure from that trend over the course of the 20th century, indicating that neither 20th century anthropogenic CO_2 emissions nor 20th century warming significantly impacted rainfall in the Mexican state of Chihuahua.

Cleaveland *et al*. (2003) constructed a winter-spring (November-March) precipitation history for the period 1386-1993 for Durango, Mexico, based on earlywood width chronologies of Douglas-fir tree rings collected at two sites in the Sierra Madre Occidental. They report that this record "shows droughts of greater magnitude and longer duration than the worst historical drought that occurred in the 1950s and 1960s." These earlier dramatic droughts included the long dry spell of the 1850s-1860s and what they called the megadrought of the mid- to late-16th century. Their work clearly demonstrates, therefore, that the worst droughts of the past 600 years did not occur during the period of greatest warmth. Instead, they occurred during the Little Ice Age, which was perhaps the coldest period of the current interglacial.

Going back further in time, Hodell *et al*. (1995) had provided evidence for a protracted drought during the Terminal Classic Period of Mayan civilization (AD 800-1000), based on their analysis of a sediment core retrieved in 1993 from Lake Chichanacanab in the center of the northern Yucatan Peninsula of Mexico. Subsequently, based on two additional sediment cores retrieved from the same location in 2000, Hodell *et al*. (2001) determined that the massive drought likely occurred in two distinct phases (750-875 and 1000-1075). Reconstructing the climatic history of the region over the past 2,600 years and applying spectral analysis to the data also revealed a significant recurrent drought periodicity of 208 years that matched well with a cosmic ray-produced ^{14}C record preserved in tree rings, which is believed to reflect variations in solar activity; and because of the good correspondence between the two data sets, they concluded that "a significant component of century-scale variability in Yucatan droughts is explained by solar forcing."

Working in central Mexico, Therrell *et al*. (2006) "developed a continuous, exactly dated, tree-ring reconstruction of maize yield variability" over the period 1474 to 2001 in an effort to provide "new insight into the history of climate and food availability in the heartland of the Mesoamerican cultural province." This work was made possible by latewood-width data they derived from what they describe as "the second-most southerly native stand of Douglas-fir (*Pseudtosuga menziesii*) trees known in the Americas." In addition, the authors compared their reconstruction to "historical records of crop failure and famine in order to cross-validate the tree-ring and historical records."

Therrell *et al*.'s plot of reconstructed drought-induced maize-yield anomalies exposed a total of seven major decadal-scale yield shortfalls over the past 500 years, with a mean rate of occurrence of 1.5 per century over the 400-year period AD 1500-1900. Over the 20th century, however, there was only one such multi-year famine, and its magnitude paled in comparison to that of the average such event of the preceding four centuries. Thus, the so-called unprecedented warming of the 20th century did not produce the alarmist-predicted effect on drought in central Mexico. In fact, the threat of major drought-induced famines in this part of the world appears to have *lessened* with increased warming.

Moving into South America, Webster *et al*. (2007) removed an active stalagmite (MC01) from the entrance chamber of Macal Chasm – a cave on the Vaca Plateau west of the Rio Macal in the Cavo District of Belize near the border with Guatemala (~17°N, 89°W) – from which the authors obtained "reliably dated reflectance, color, luminescence, and C and O stable isotope records for the period from 1225 BC to the present." Upon examination of the record, they found that the interval "from AD 750 to 1150 was the most prolonged dry phase in our 3,300-year record," which period of time corresponds well with the MWP's mean time of occurrence around the globe, which period, in their words, "coincided with the collapse of the Maya civilization." More specifically, they say their data depict "a series of droughts centered at about AD 780, 910, 1074, and 1139," with "successive droughts increasing in severity."

Mundo *et al*. (2012) employed 43 new and updated tree-ring chronologies from a network of *Araucaria araucana* and *Austrocedrus chilensis* trees in reconstructing the October-June mean streamflow of Argentina's Neuquen River over the 654-year period AD 1346-2000. According to the eight researchers who conducted this study, in terms of the frequency, intensity and duration of droughts and pluvial events, they say "the 20th century contains some of the driest and wettest annual to decadal-scale events in the last 654 years." *However* – and it's a very *big* however – they report that "longer and more severe events were recorded in previous centuries," the significance of which becomes apparent when it is recognized that the bulk of the 554 years that preceded the 20th century were part of the much colder Little Ice Age. Therefore, it would appear that, if anything, the "unprecedented" global warming of the past century has brought Argentina's Neuquen River *less* extreme streamflow conditions, which is just the *opposite* of what model-based projections suggest should have happened.

Masiokas *et al*. (2012) developed the first reconstruction and quantitative analysis of variations in snow accumulation of the past eight-and-a-half centuries in the Andes between 30° and 37°S. This record was based on "instrumental rainfall and streamflow data from adjacent lowlands, a variety of documentary records, and century-long tree-ring series of precipitation-sensitive species from the western side of the Andes," representing "the first attempt to reconstruct annually-resolved, serially complete snowpack variations spanning most of the past millennium in the Southern Hemisphere," which record "allows testing the relative severity of recent 'extreme' conditions in a substantially longer context."

Based on their findings, the eight researchers who conducted the study report that "variations observed in the last 60 years are not particularly anomalous when assessed in a multi-century context," noting that both extreme high and low snowpack values "have not been unusual when assessed in the context of the past eight centuries." Indeed, they say "the most extreme dry decades are concentrated between the late 16th century and the mid-18th century," and there were "decade-long periods of high snowpack levels that equaled or probably surpassed those recorded during the past six decades."

Shifting to a different continent, Therrell *et al*. (2006) developed what they describe as "the first tree-ring reconstruction of rainfall in tropical Africa using a 200-year regional chronology based on samples of *Pterocarpus angolensis* [a deciduous tropical hardwood known locally as Mukwa] from Zimbabwe." This project revealed "a decadal-scale drought reconstructed from 1882 to 1896 matches the most severe sustained drought during the instrumental period (1989-1995)," and "an even more severe drought is indicated from 1859 to 1868 in both the tree-ring and documentary data." They report, for example, the year 1860 (which was the most droughty year of the entire period), was described in a contemporary account from Botswana (where part of their tree-ring chronology originated) as "a season of 'severe and universal drought' with 'food of every description' being 'exceedingly scarce' and the losses of cattle being 'very severe' (Nash and Endfield, 2002)," while at the other end of the moisture spectrum, Therrel *et al*. report "a 6-year wet period at the turn of the nineteenth century (1897-1902) exceeds any wet episode during the instrumental era." Consequently, for a large part of central southern Africa, it is clear that the supposedly unprecedented global warming of the 20th century did not result in an intensification of either extreme dry or wet periods. If anything, just the *opposite* appears to have occurred.

Similar findings were reported by Esper *et al*. (2007). In prefacing their work, they stated that "analysis of the PDSI [Palmer Drought Severity Index], a standardized measure of surface moisture conditions, revealed distinct 20th century aridity changes in vulnerable NW Africa, including a sharp downward trend towards drier conditions in the 1980s (Luterbacher *et al*., 2006)," but they indicated that "a high-resolution long-term reconstruction that could place current conditions in the context of the past millennium is missing for N Africa," which was exactly what the authors hoped they could remedy. More specifically, Esper *et al*. re-used *Cedrus atlantica* tree-ring data generated in the 1980s (Glueck and Stockton, 2001) and combined these measurements with a major update made in 2002, which allowed "analysis of tree growth and instrumental data during the current drought episode in comparison to PDSI estimates back to AD 1049."

The six scientists who conducted this study reported that "PDSI values were above average for most of the 1450-1980 period, which let recent drought appear exceptional." However, they say the long-term results they obtained indicate the "pluvial episode of the past millennium was preceded by generally drier conditions back to 1049," leading them to state the late 20th-century drought "appears more typical when associated with conditions before 1400." In addition, they concluded their paper by stating that the "ultimate drivers" for the medieval hydroclimate pattern that led to the earlier drought conditions in Morocco "seemed to be high solar irradiance and low volcanic forcings," citing Emile-Geay *et al*. (2007).

Probing some 1500 years into the past was the study of Holmes *et al*. (1997), who wrote that since the late 1960s, the African Sahel had experienced "one of the most persistent droughts recorded by the entire global meteorological record." However, in a high-resolution study of a sediment sequence extracted from an oasis in the Manga Grasslands of northeast Nigeria, they too determined that "the present drought is not unique and that drought has recurred on a centennial to interdecadal timescale during the last 1500 years."

Moving to Asia, Jiang *et al*. (2005) analyzed historical documents to produce a time series of flood and drought occurrences in eastern China's Yangtze Delta since AD 1000. Their work also revealed that alternating wet and dry episodes occurred throughout this lengthy period; and the data demonstrate that droughts and floods usually occurred in the spring and autumn seasons of the same year, with the most rapid and strongest of these fluctuations occurring during the Little Ice Age (1500-1850), as opposed to the preceding Medieval Warm Period and the following Current Warm Period.

Writing as background for their work, Cai *et al*. (2014) state "investigations of the natural climate background of the Chinese Loess Plateau (CLP) are crucial for understanding the processes and characteristics of climate change in this region as well as the current status of the climate." Thus, they set out to conduct a historical analysis of drought for this region, attempting to answer the following two key questions: (1) "Did the drought severity or frequency increase in response to the global warming?" and (2) Is the present drought in the region "unprecedented during the last three centuries?" The analysis was made possible by the development of a new regional tree-ring chronology from Chinese pine trees located in three different sites of the Lingkong Mountain area (112°10'-112°15' E, 36°31'-36°43' N) of the southeast CLP. The resulting chronology was positively correlated with monthly Palmer Drought Severity Index (PDSI) values obtained from meteorological data for the region over the period 1954-2005. Based on that correlation, the researchers were able to reconstruct a record of historic PDSI since 1703 AD.

Cai *et al*. report the existence of seven dry periods and six wet periods in the 306-year reconstruction. The driest interval occurred between 1867 and 1932, while the wettest interval followed between 1934 and 1957. With respect to the most recent drought (1993-2008), there was nothing unique or unprecedented about it. Rather, the team of researchers report it is "still within the frame of natural climate variability." In addition, multi-taper spectral analysis identified periodicities of 37.9 and 102 years in the reconstructed PDSI record, which Cai *et al*. say "resemble the 35-year Bruckner (Raspopov *et al*., 2004) and Gleissberg cycles of solar activity (Sonett *et al*., 1990; Braun *et al*., 2005), respectively." Further analysis of the PDSI reconstruction and the NOAA sunspot time series revealed a significant correlation between the two variables that Cai *et al*. say "convincingly [supports] the influence of solar activity on moisture variations in the Lingkong Mountain area." Thus, the results of their analysis speak for themselves in answering the two questions posed by the authors at the beginning of their study. Recent drought in the CLP is not unprecedented and is more likely the product of natural, as opposed to anthropogenic, forcings.

Kalugin *et al*. (2005) utilized sediment cores from Lake Teletskoye in the Altai Mountains of Southern Siberia to produce a multi-proxy climate record spanning the past 800 years. With respect to moisture and precipitation, Kalugin *et al*. state that the period between 1210 and 1480 was more humid than today, while the period between 1480 and 1840 was more arid. In addition, they report three episodes of multi-year drought (1580-1600, 1665-1690 and 1785-1810), which findings are in agreement with other historical data and tree-ring records from the Mongolia-Altai region (Butvilovskii, 1993; Jacoby *et al*., 1996; Panyushkina *et al*., 2000). Consequently, this study also proves problematic in attempting to support the claim that global warming will lead to more frequent and more severe droughts, as all of the major multi-year droughts detected in this study occurred during the cool phase of the 800-year record.

In another study, Kim *et al*. (2009) developed a 200-year history of precipitation measured at Seoul, Korea (1807 to 2006), along with the results of a number of "progressive methods for assessing drought severity from diverse points of view," starting with (1) the Effective Drought Index (EDI) developed by Byun and Wilhite (1999), which Kim *et al*. describe as "an intensive measure that considers daily water accumulation with a weighting function for time passage," (2) a Corrected EDI that "considers the rapid runoff of water resources after heavy rainfall" (CEDI), (3) an Accumulated EDI that "considers the drought severity and duration of individual drought events" (AEDI), and (4) a Year-accumulated negative EDI "representing annual drought severity" (YAEDI).

These researchers' precipitation history and two of their drought severity histories are presented, in that order, in Figures 5 and 6.

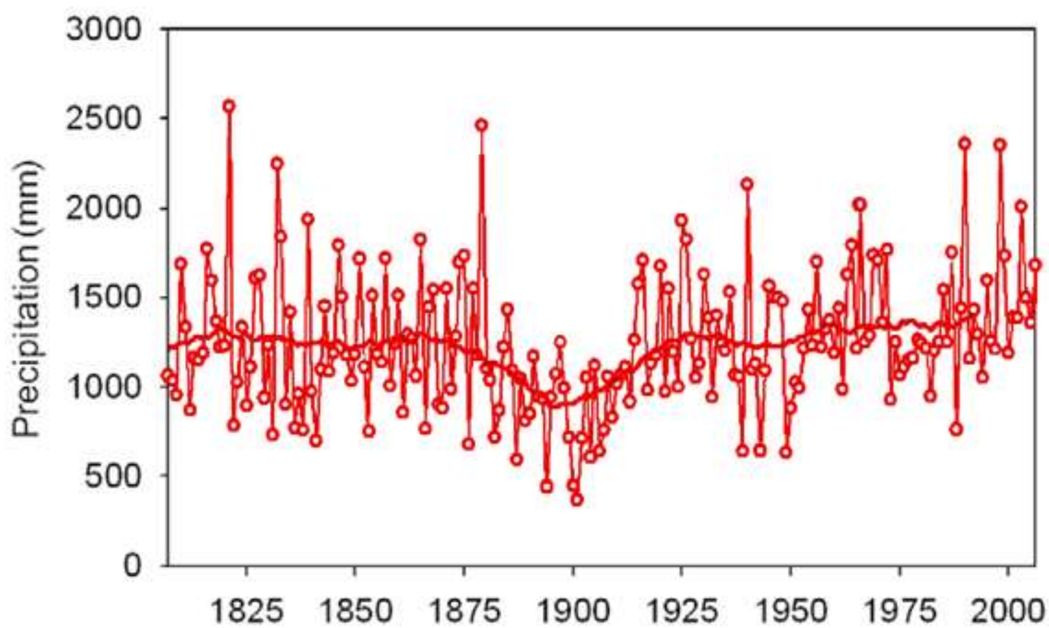

Figure 5. *Annual precipitation history at Seoul, Korea, where the solid line represents a 30-year moving-average. Adapted from Kim et al. (2009).*

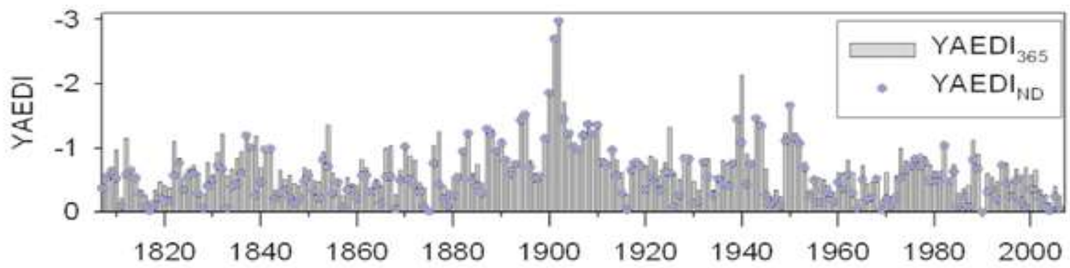

Figure 6*. Annual "dryness" history at Seoul, Korea, represented by YAEDI365 (Sum of daily negative EDI values divided by 365, represented by bars) and YAEDIND (Sum of daily negative EDI values divided by total days of negative EDI, represented by open circles). Adapted from Kim et al. (2009).*

In viewing the results depicted in Figures 5 and 6, it is clear that the only major multi-year deviation from long-term normalcy is the decadal-scale decrease in precipitation and ensuing drought, each of which achieved their most extreme values (low in the case of precipitation, high in the case of drought) in the vicinity of AD 1900, well before the 20th century rise in atmospheric CO_2 and global temperatures. The significant post-Little Ice Age warming of the planet, therefore, had essentially no effect at all on the long-term histories of either precipitation or drought at Seoul, Korea.

Sinha *et al*. (2011) explored the issue of drought in India. In writing as background for their study they warn the return of a severe drought to the region could pose "a particular serious threat for the predominantly agrarian-based societies of monsoon Asia, where the lives of billions of people are tightly intertwined with the annual monsoon cycle." And as a result of such concern, the group of eight researchers, hailing from China, Germany and the United States, review in great detail what is known about the history of the monsoon, relying heavily on the work of Sinha *et al*. (2007) and Berkelhammer *et al*. (2010).

Based on their review, Sinha *et al*. (2011) state that "proxy reconstructions of precipitation from central India, north-central China [Zhang *et al*., 2008], and southern Vietnam [Buckley *et al*., 2010] reveal a series of monsoon droughts during the mid-14th-15th centuries that each lasted for several years to decades," and they say "these monsoon megadroughts have no analog during the instrumental period." They also report that "emerging tree ring-based reconstructions of monsoon variability from SE Asia (Buckley *et al*., 2007; Sano *et al*., 2009) and India (Borgaonkar *et al*., 2010) suggest that the mid-14th-15th century megadroughts were the first in a series of spatially widespread megadroughts that occurred during the Little Ice Age," and they say they "appear to have played a major role in shaping significant regional societal changes at that time." Among these upheavals, they make special mention of "famines and significant political reorganization within India (Dando, 1980; Pant *et al*., 1993; Maharatna, 1996), the collapse of the Yuan dynasty in China (Zhang *et al*., 2008), the Rajarata civilization in Sri Lanka (Indrapala, 1971), and the Khmer civilization of Angkor Wat fame in Cambodia (Buckley *et al*., 2010)," noting that the evidence suggests that "monsoon megadroughts may have played a major contributing role in shaping these societal changes." And contrary to conventional climate-alarmist thinking on the subject, all of these droughts occurred prior to the modern increase of atmospheric CO_2 and the supposedly unprecedented warming of the past few decades.

Over in Europe and concentrating on Central Scandinavia, Linderholm and Chen (2005) derived a 500-year history of winter (September-April) precipitation from tree-ring data obtained within the Northern Boreal zone of the region. This chronology indicated that below average precipitation was observed during the periods 1504-1520, 1562-1625, 1648-1669, 1696-1731, 1852-1871 and 1893-1958, with the lowest values occurring at the beginning of the record and at the beginning of the 17th century. These results clearly demonstrate that for this portion of the European continent, 20th-century global warming did not result in more frequent or more severe droughts.

In a related study conducted in east central Sweden, Linderholm and Molin (2005) analyzed two independent precipitation proxies, one derived from tree-ring data and one from a farmer's diary, to produce a 250-year record of summer (Jun-Aug) precipitation. This work indicated there had been a high degree of variability in summer precipitation on inter-annual to decadal time scales throughout the record, but with the past century exhibiting less variability than the 150 years that preceded it. One period that stood out vividly was a persistent dry episode between 1806 and 1832, when the tree-ring history revealed its longest consecutive period of below-average tree growth, which was associated with a concomitant period of drought that was documented in the farmer's diary.

Moving further in the continent toward Germany, Wilson *et al*. (2005) used the regional curve standardization technique to develop a summer (March-August) precipitation chronology from living and historical ring-widths of trees in the Bavarian Forest region of southeast Germany for the period 1456-2001. This technique captured low frequency variations that indicate the region was substantially drier than the long-term average during the periods 1500-1560, 1610-1730 and 1810-1870, all of which intervals were much colder than the bulk of the 20th century. Thus, these results, too, fly in the face of model-based predictions.

Another study of interest concerns the Danube River in western Europe, where several researchers had studied the precipitation histories of adjacent regions and suggested that an anthropogenic signal was present in the latter decades of the 20th century, and that it was responsible for that period's supposedly drier conditions. Determined to investigate further, Ducic (2005) examined these claims by analyzing observed and reconstructed discharge rates of the river near Orsova, Serbia over the period 1731-1990. This work revealed that the lowest 5-year discharge value in the pre-instrumental era (1831-1835) was practically equal to the lowest 5-year discharge value in the instrumental era (1946-1950), and that the driest decade of the entire 260-year period was 1831-1840. What is more, the discharge rate for the last decade of the record (1981-1990), which prior researchers had claimed was anthropogenically-influenced, was found to be "completely inside the limits of the whole series," in Ducic's words, and only 0.7% less than the 260-year mean, leading to the conclusion that "modern discharge fluctuations do not point to dominant anthropogenic influence." In fact, Ducic's correlative analysis suggests the detected cyclicity in the record could "point to the domination of the influence of solar activity."

Also of note, Pfister *et al*. (2006) identified extremely low water stages within the Upper Rhine River Basin via hydrological measurements made since 1808 at Basel, Switzerland, while "for the period prior to 1808, rocks emerging in rivers and lakes in the case of low water were used along with narrative evidence for assessing extreme events." This work revealed that "29 severe winter droughts are documented since 1540," which events, in their words, "occurred after a succession of four months with below-average precipitation" associated with "persistent anticyclones centered over Western Europe." Of most interest, in this regard, was their finding that "severe winter droughts were relatively rare in the 20th century compared to the former period, which is due to increased winter temperature and precipitation." And in discussing the generality of their findings, they note that "extended droughts in the winter half-year in Central Europe were more frequent, more persistent and more severe during the Little Ice Age than in the preceding 'Medieval Warm Period' and the subsequent 'warm 20th century' (Pfister, 2005)," which facts suggest a relationship just the *opposite* of what is typically assumed by climate models to be the case.

In summation, the aforementioned studies demonstrate the need to have long-term (millennial-scale) records of droughts in order to determine how exceptional 20th-century changes in their characteristics might have been, which can help to determine whether there is compelling reason to attribute such changes to historical increases in the atmospheric concentrations of various greenhouse gases. And considering the findings presented above, real-world evidence suggests that the global warming of the past century or so has *not* led to either a greater frequency or severity of drought. Indeed, even the worst droughts in recorded meteorological history do not seem to have been any worse (in fact, they are actually much milder) than droughts that occurred in the historic past. And as a result, there is little reason to put any credence whatsoever in the potential for global warming to lead to more frequent or severe droughts.

3.2.3. Other Factors Driving Observed Trends

A number of researchers have identified various *natural* forcings that may help to explain the occurrence of historical droughts. These forcings have operated for hundreds and even *thousands* of years independently of the atmosphere's CO_2 concentration; and they must be accounted for in drought attribution studies.

Among the most commonly-mentioned of these forcings are those related to various solar phenomena. In this regard, for example, Paulsen *et al*. (2003) employed high-resolution stalagmite records of $\delta^{13}C$ and $\delta^{18}O$ from Buddha Cave "to infer changes in climate in central China for the last 1270 years in terms of warmer, colder, wetter and drier conditions." Among the climatic episodes evident in their data were "those corresponding to the Medieval Warm Period, Little Ice Age and 20th-century warming, lending support to the global extent of these events." More specifically, their record begins in the depths of the Dark Ages Cold Period, which ends about AD 965 with the commencement of the Medieval Warm Period, which continues to approximately AD 1475, whereupon the Little Ice Age sets in and holds sway until about AD 1825, after which the warming responsible for the Modern Warm Period begins.

With respect to hydrologic balance, the last part of the Dark Ages Cold Period was characterized as wet. It, in turn, was followed by a dry, a wet, and another dry interval in the Medieval Warm Period, which was followed by a wet and a dry interval in the Little Ice Age, and finally a mostly-wet but highly moisture-variable Modern Warm Period. Paulsen *et al*.'s data also reveal a number of other cycles superimposed on the major millennial-scale cycle of temperature and the centennial-scale cycle of moisture, most of which higher-frequency cycles they attribute to solar phenomena, concluding that the summer monsoon over eastern China, which brings the region much of its precipitation, may "be related to solar irradiance."

The significance of this study with respect to the present discussion on drought resides in the fact that the authors' data clearly indicate that Earth's climate is determined by a conglomerate of cycles within cycles, all of which are essentially independent of the air's CO_2 concentration; and it demonstrates that the multi-century warm and cold periods of the planet's millennial-scale oscillation of temperature may have both wetter and drier periods embedded within them. Consequently, it can be appreciated that warmth alone is not a sufficient condition for the concomitant occurrence of the dryness associated with drought.

In another study suggestive of a solar-drought link, Springer *et al*. (2008) constructed a multi-decadal-scale history of east-central North America's hydroclimate over the past 7,000 years, based on Sr/Ca ratios and δ^{13}C data obtained from stalagmite BCC-002 of Buckeye Creek Cave (BCC) in West Virginia, USA. In doing so, the authors detected seven significant mid- to late-Holocene droughts that "correlate with cooling of the Atlantic and Pacific Oceans as part of the North Atlantic Ocean ice-rafted debris [IRD] cycle, which has been linked to the solar irradiance cycle," as per Bond *et al*. (1997, 2001). In addition, they found that "the Sr/Ca and δ^{13}C time series display periodicities of ~200 and ~500 years," and that "the ~200-year periodicity is consistent with the de Vries (Suess) solar irradiance cycle," and that the ~500-year periodicity is likely "a harmonic of the IRD oscillations." They also report that actual "cross-spectral analysis of the Sr/Ca and IRD time series yields statistically significant coherencies at periodicities of 455 and 715 years," which latter values "are very similar to the second (725-years) and third (480-years) harmonics of the 1450 ± 500-years IRD periodicity." Such findings, in the words of the five researchers, "corroborate works indicating that millennial-scale solar-forcing is responsible for droughts and ecosystem changes in central and eastern North America (Viau *et al*., 2002; Willard *et al*., 2005; Denniston *et al*., 2007)," and that their high-resolution time series "provide much stronger evidence in favor of solar-forcing of North American drought by yielding unambiguous spectral analysis results."

In another study, Woodhouse and Overpeck (1998) reviewed what is known about the frequency and severity of drought in the central United States over the last two thousand years based upon empirical evidence of drought from various proxy indicators. Their study indicated the presence of numerous "multidecadal- to century-scale droughts," leading them to conclude that "twentieth-century droughts are not representative of the full range of drought variability that has occurred over the last 2000 years." In addition, they noted that the 20th century was characterized by droughts of "moderate severity and comparatively short duration, relative to the full range of past drought variability."

With respect to the *causes* of drought, Woodhouse and Overpeck suggest a number of different possibilities that either directly or indirectly induce changes in atmospheric circulation and moisture transport. However, they caution that "the causes of droughts with durations of years (i.e., the 1930s) to decades or centuries (i.e., paleodroughts) are not well understood." Hence, they conclude that "the full range of past natural drought variability, deduced from a comprehensive review of the paleoclimatic literature, suggests that droughts more severe than those of the 1930s and 1950s are likely to occur in the future," and, it might be added, irrespective of whatever the air's CO_2 concentration or temperature might be doing in future years.

Gray *et al*. (2003) examined fifteen tree ring-width chronologies used in previous reconstructions of drought for evidence of low-frequency variations in five regional composite precipitation histories in the central and southern Rocky Mountains. In doing so, they found "strong multi-decadal phasing of moisture variation was present in all regions during the late 16th-century megadrought," and that "oscillatory modes in the 30-70 year domain persisted until the mid-19th century in two regions, and wet-dry cycles were apparently synchronous at some sites until the 1950s drought." And they thus speculate that "severe drought conditions across consecutive seasons and years in the central and southern Rockies may ensue from coupling of the cold phase Pacific Decadal Oscillation with the warm phase Atlantic Multidecadal Oscillation," which is something they envision as having happened in both the severe 1950s drought and the late 16th-century megadrought. Thus, there is reason to believe that episodes of extreme dryness in this part of the country may be driven in part by naturally-recurring climate "regime shifts" in the Pacific and Atlantic Oceans.

Also suggesting that ocean oscillations might bear a good deal of the blame for large-scale drought in the western U.S. was Seager (2007), who studied the global context of the drought that affected nearly the entire United States, northern Mexico and the Canadian Prairies—but most particularly the American West—between 1998 and 2004. Based on atmospheric reanalysis data and ensembles of climate model simulations forced by global or tropical Pacific sea surface temperatures over the period January 1856 to April 2005, Seager compared the climatic circumstances of the recent drought with those of the five prior great droughts of North America: (1) the Civil War drought of 1856-65, (2) the 1870s drought, (3) the 1890s drought, (4) the great Dust Bowl drought, and (5) the 1950s drought. In doing so, Seager reports the 1998-2002 period of the recent drought "was most likely caused by multiyear variability of the tropical Pacific Ocean," noting the recent drought "was the latest in a series of six persistent global hydroclimate regimes, involving a persistent La Niña-like state in the tropical Pacific and dry conditions across the mid-latitudes of each hemisphere."

Of additional note, there was no aspect of Seager's study that implicates global warming, either CO_2-induced or otherwise, as a cause of—or contributor to—the great turn-of-the-20th-century drought that affected large portions of North America. Seager notes, for example, that "although the Indian Ocean has steadily warmed over the last half century, this is *not* implicated as a cause of the turn of the century North American drought because the five prior droughts were associated with cool Indian Ocean sea surface temperatures." In addition, the five earlier great droughts occurred during periods when the mean *global* temperature was *also* significantly cooler than what it was during the last great drought.

Working in eastern Canada, Girardin *et al*. (2004) developed a 380-year reconstruction of the Canadian Drought Code (CDC, a daily numerical rating of the average moisture content of deep soil organic layers in boreal conifer stands that is used to monitor forest fire danger) for the month of July, based on 16 well replicated tree-ring chronologies from the Abitibi Plains of eastern Canada just below James Bay. Cross-continuous wavelet transformation analyses of these data, in their words, "indicated coherency in the 8-16 and 17-32-year per cycle oscillation bands between the CDC reconstruction and the Pacific Decadal Oscillation prior to 1850," while "following 1850, the coherency shifted toward the North Atlantic Oscillation."

These results led them to suggest that "the end of [the] 'Little Ice Age' over the Abitibi Plains sector corresponded to a decrease in the North Pacific decadal forcing around the 1850s," and that "this event could have been followed by an inhibition of the Arctic air outflow and an incursion of more humid air masses from the subtropical Atlantic climate sector," which may have helped reduce fire frequency and drought severity. In this regard, they further note that several other paleo-climate and ecological studies have suggested that "climate in eastern Canada started to change with the end of the 'Little Ice Age' (~1850)," citing the works of Tardif and Bergeron (1997, 1999), Bergeron (1998, 2000) and Bergeron *et al*. (2001), while further noting that Bergeron and Archambault (1993) and Hofgaard *et al*. (1999) have "speculated that the poleward retreat of the Arctic air mass starting at the end of the 'Little Ice Age' contributed to the incursion of moister air masses in eastern Canada."

In another paper examining historic droughts in the U.S., Herweijer *et al*. (2006) find evidence for a "linkage between a colder eastern equatorial Pacific and persistent North American drought over the last 1,000 years," noting further that "Rosby wave propagation from the cooler equatorial Pacific amplifies dry conditions over the USA." In addition, they report that after using "published coral data for the last millennium to reconstruct a NINO 3.4 history," they applied "the modern-day relationship between NINO 3.4 and North American drought ... to recreate two of the severest Mediaeval 'drought epochs' in the western USA," again demonstrating the importance of understanding other forcings on drought independent of atmospheric CO_2.

Finally, Morengo (2009) worked with hydrometeorological indices for the Amazon basin and its several sub-basins in an effort designed "to explore long-term variability of climate since the late 1920s and the presence of trends and/or cycles in rainfall and river indices in the basin," which analyses were based on northern and southern Amazonian rainfall data originally developed by Marengo (1992) and Marengo and Hastenrath (1993), and which were subsequently updated by Marengo (2004). According to the Brazilian researcher, the results of this effort indicate "no systematic unidirectional long-term trends towards drier or wetter conditions [were] identified." Instead, he found that "the rainfall and river series show variability at inter-annual scales." And of the patterns he uncovered, Morengo writes that they are "characteristic of decadal and multi-decadal modes," which he describes as "indicators of natural climate variability" that are linked to the El Niño Southern Oscillation, "rather than any unidirectional trend towards drier conditions (as one would expect, due to increased deforestation or to global warming)."

Clearly, numerous studies fail to support the climate-alarmist claim that CO_2-induced global warming is increasing both the frequency and severity of drought conditions around the world; and the many findings presented above *persuasively demonstrate* that several other factors – unrelated to rising CO_2 – *dominate* historical drought records. And, therefore, proper accounting for their influence must be conducted before assessing a potential role for anthropogenic CO_2.

3.3. Storms

Several researchers have investigated how storms have responded to the global warming of the past few decades. This section highlights the results of numerous empirical analyses that shed light on the climate-alarmist claim that CO_2-induced global warming is leading to more frequent and intensified storm events around the globe. The studies discussed here clearly indicate there is nothing unusual about storms of the modern era. Severe storms of the most recent decades have historic analogs in the distant and not-so-distant past, when the atmosphere's CO_2 concentration was much lower than it is presently. As such, the materials presented below do not support the climate-alarmist contention that the ongoing rise in the air's CO_2 content is having a measurable impact on extratropical (non-hurricane) storms.

Hayden (1999) investigated storm frequencies in North America between 25° and 55°N latitude and 60° and 125°W longitude from 1885 to 1996. Over this 112-year period, he reported that large regional changes in storm occurrences were observed; but when integrated over the entire geographic area, no net change in storminess was evident.

Zhang *et al*. (2000) used ten long-term records of storm surges derived from hourly tide gauge measurements to calculate annual values of the number, duration and integrated intensity of storms along the east coast of the United States. Their analysis did not reveal any trends in storm activity during the twentieth century, which they say is suggestive of "a lack of response of storminess to minor global warming along the U.S. Atlantic coast during the last 100 yr."

Writing as background for their study, Changnon and Changnon (2006) state that (1) "global climate models predict that more weather extremes will be a part of a changed climate due to greenhouse gases," that (2) such a climate change "is anticipated to result in alterations of cyclone activity over the Northern Hemisphere (Lawson, 2003)," and that (3) "a change in the frequency, locations, and/or intensity of extratropical cyclones in the mid-latitudes would alter the incidence of snowstorms," citing the work of Trenberth and Owen (1999). Thus, they decided to see if real-world data could shed any light on the veracity of these predictions, conducting "a climatological analysis of the spatial and temporal distributions of ... damaging snowstorms and their economic losses … using property-casualty insurance data that consist of highly damaging storm events, classed as catastrophes by the insurance industry, during the 1949-2000 period."

In describing their findings, the father-and-son research team reports that "the incidence of storms peaked in the 1976-1985 period," but that snowstorm incidence "exhibited no up or down trend during 1949-2000," although national monetary losses did have a significant upward time trend indicative of "a growing societal vulnerability to snowstorms." The two researchers thus concluded their paper by stating that "the temporal frequency of damaging snowstorms during 1949-2000 in the United States does not display any increase over time, indicating that either no [CO_2-induced] climate change effect on cyclonic activity has begun, or if it has begun, altered conditions have not influenced the incidence of snowstorms."

Changnon (2003) utilized an extensive data set on thunderstorm days covering the period 1896-1995 to assess long-term temporal variations in thunderstorm activity at 110 first-order weather reporting stations scattered across the United States. By dividing the data into five 20-year segments, Changnon found that "the 1936-1955 period was the nation's peak of storm activity during the 100-year period ending in 1995." During this central 20-year period, 40% of the 110 first-order weather stations experienced their greatest level of storm activity, whereas during the final 20-year period from 1976-1995, only 15% of the stations experienced their greatest level of storm activity.

Gulev *et al*. (2001) utilized sea level pressure from NCEP/NCAR reanalysis data for the period 1958-1999 to develop a winter (January-March) climatology of cyclones (storms) for the Northern Hemisphere, from which they statistically analyzed only those cyclones that reached a sea level pressure of 1,000 mb or lower. Their results indicated that the yearly mean number of winter cyclones for the period was 234, although there was pronounced interannual and spatial variability in the record. Linear trend estimates indicated a statistically significant (95% level) annual decline of 1.2 cyclones per year, suggesting there were 50 fewer cyclones in the Northern Hemisphere winter at the end of the record than there were during the prior 42 years (Figure 7). Additional data analyses suggest that Northern Hemisphere winter cyclones are intensifying at quicker rates and are reaching greater maximum depths (lower sea level pressure) at the end of the record than they were at the beginning of the record. However, the wintertime cyclones are also experiencing shorter life cycles, dissipating more quickly at the end of the record than at the beginning.

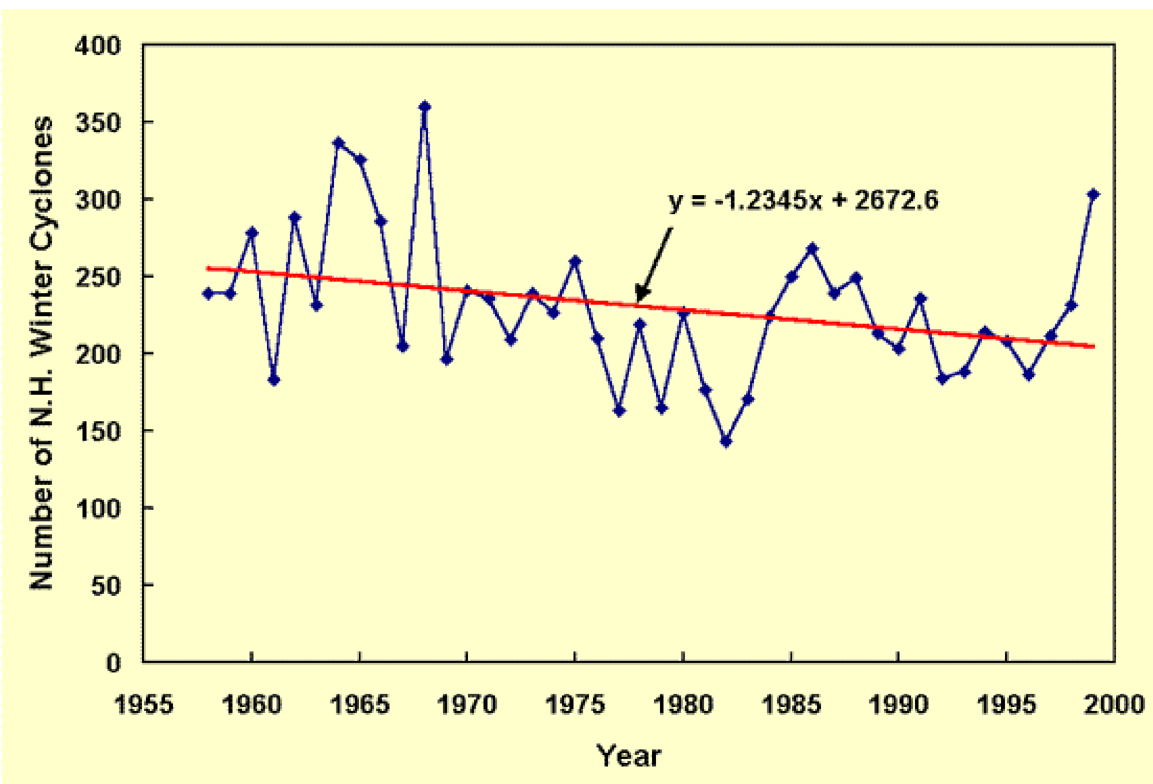

Figure 7. *Yearly number of Northern Hemisphere cyclones over the period 1958-1999. Adapted from Gulev et al. (2001).*

Winter storms in the Northern Hemisphere at the end of the 20th century thus appear to have been maturing faster, but dissipating quicker, than they were four decades earlier. Could this change be the result of global warming? According to the researchers who performed the analyses, the phenomenon is probably connected to large-scale features of atmospheric variability, such as the North Atlantic Oscillation and the North Pacific Oscillation. As for the large decrease reported in the annual number of Northern Hemisphere cyclones over the 42-year period, this observation is in direct opposition to model-based extreme weather predictions, which suggest that the frequency of such events will increase as a result of global warming.

Recognizing that "media reports in recent years have left the public with the distinct impression that global warming has resulted, and continues to result, in changes in the frequencies and intensities of severe weather events," Hage (2003) set out to test this hypothesis in the prairie provinces of Alberta and Saskatchewan in western Canada. This was accomplished by utilizing "previously unexploited written resources such as daily and weekly newspapers and community histories" to establish a data base adequate for determining long-term trends of all destructive windstorms (primarily thunderstorm-based tornadoes and downbursts) for the region over the period 1882 to 2001. And the results of this study revealed that "all intense storms showed no discernible changes in frequency after 1940," while prior to that time they had exhibited minor maxima.

Focusing on the region of northern and northwestern Scotland, Dawson *et al*. (2002) searched daily meteorological records from Stornoway (Outer Hebrides), Lerwick (Shetland Islands), Wick (Caithness) and Fair Isle (west of the Shetland Islands) for all data pertaining to gale-force winds over the period 1876-1996, which they used to construct a history of storminess for that period for northern and northwestern Scotland. This history indicated that although North Atlantic storminess and associated wave heights had indeed increased over the prior two decades, storminess in the North Atlantic region "was considerably more severe during parts of the nineteenth century than in recent decades." In addition, whereas the modern increase in storminess appeared to be associated with a spate of substantial positive values of the North Atlantic Oscillation (NAO) index, they say "this was not the case during the period of exceptional storminess at the close of the nineteenth century." During that earlier period, the conditions that fostered modern storminess were apparently overpowered by something even more potent, i.e., cold temperatures, which in the view of Dawson *et al*. led to an expansion of sea ice in the Greenland Sea that expanded and intensified the Greenland anticyclone, which in turn led to the North Atlantic cyclone track being displaced farther south. Additional support for this view is provided by Clarke *et al*. (2002), who postulated that a southward spread of sea ice and polar water results in an increased thermal gradient between 50°N and 65°N that intensifies storm activity in the North Atlantic and supports dune formation in the Aquitaine region of southwest France.

The results of these two studies suggest that the increased storminess and wave heights observed in the European sector of the North Atlantic Ocean over the past two decades are not the result of global warming. Rather, they are associated with the most recent periodic increase in the NAO index. Furthermore, a longer historical perspective reveals that North Atlantic storminess was even more severe than it is now during the latter part of the nineteenth century, when it was significantly colder than it is now. In fact, the storminess of that much colder period was so great that it was actually decoupled from the NAO index. Hence, the long view of history suggests that the global warming of the past century or so has actually led to an overall *decrease* in North Atlantic storminess.

In introducing their study of the subject, Allan *et al*. (2009) write that an analysis of a 47-year storm database by Alexander *et al*. (2005) "showed an increase in the number of severe storms in the 1990s in the United Kingdom," but that "it was not possible to say with any certainty that this was either indicative of climatic change or unusual unless it was seen in a longer-term context." Thus, in an effort to provide a longer-term context to that study, Allan *et al*. (2009) extended the database of Alexander *et al*. back to 1920, almost doubling the length of the record, after which they reanalyzed the expanded dataset for the periods of boreal autumn (October, November, December) and winter (January, February, March). And in doing so, they determined that both databases exhibited peaks in storminess in the 1920s and 1990s, with boreal autumn storms being more numerous in the 1920s and winter storms being more numerous in the 1990s. The total storm numbers for each decade are plotted in Figure 8; and as can be seen there, both the beginning and end decades of the record experienced nearly identical numbers of storms, demonstrating that the increasingly greater number of extreme storms that impacted the British Isles from the 1960s through the 1990s likely was not related to the global warming of that period.

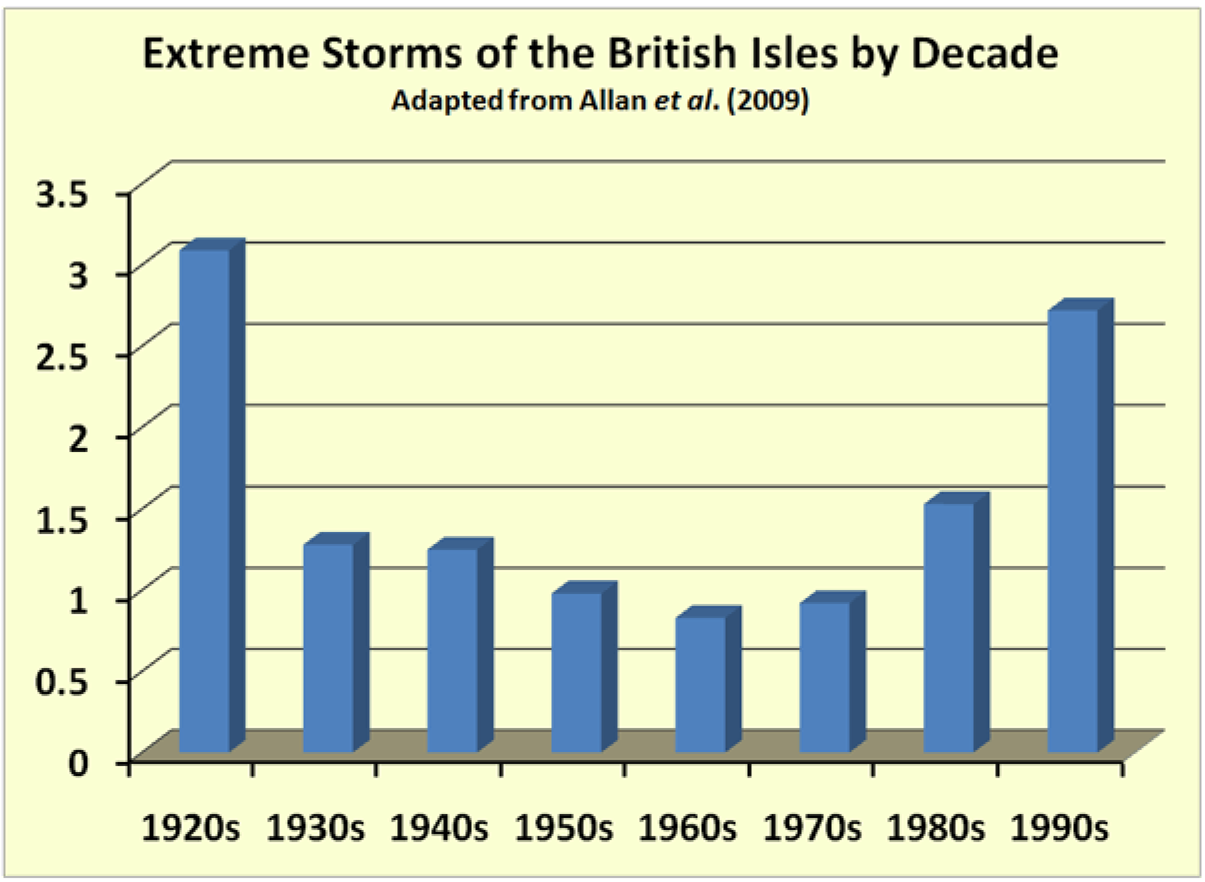

Figure 8. *Number of extreme storms impacting the British Isles in each of eight decadal periods. Created from results reported by Allan et al. (2009).*

Working in Sweden, Barring and von Storch (2004) introduced the rationale for their study by saying that with the popular perspective of anthropogenic climate change, the occurrence of extreme events such as windstorms may "create the perception that ... the storms lately have become more violent, a trend that may continue into the future." Therefore, with the intent to test this inference, and relying on data rather than perception to address the topic, the two researchers analyzed long time series of pressure readings for Lund (since 1780) and Stockholm (since 1823), analyzing (1) the annual number of pressure observations below 980 hPa, (2) the annual number of absolute pressure tendencies exceeding 16 hPa/12h, and (3) intra-annual 95th and 99th percentiles of the absolute pressure differences between two consecutive observations. And by these means they determined that the storminess time series they developed "are remarkably stationary in their mean, with little variations on time scales of more than one or two decades." In this regard, for example, they note "the 1860s-70s was a period when the storminess indices showed general higher values," as was the 1980s-90s, but that, subsequently, "the indices have returned to close to their long-term mean."

Barring and von Storch thus concluded their paper by stating that their storminess proxies "show no indication of a long-term robust change towards a more vigorous storm climate." In fact, during "the entire historical period," in their words, storminess was "remarkably stable, with no systematic change and little transient variability." Thus, it can be concluded that for much of Sweden, at least, there was no warming-induced increase in windstorms over the entire transitional period between the Little Ice Age and the Modern Warm Period, which suggests there is little reason to conclude that this non-trend would change with any further warming of the globe.

Introducing their work, Bielec-Bakowska and Piotrowicz (2013) write that "at a continental scale it is low pressure areas, especially those traveling from west to east with their associated systems of atmospheric fronts, that generally have a significant influence on European weather," as they are "often accompanied by meteorological phenomena of a violent nature, such as sudden changes of pressure and temperature, strong winds, heavy precipitation including hail, and electrical discharges," with the result that "very often these phenomena cause considerable damage to the environment and the economy and may adversely influence human health and well-being." And they add that "at a time of ongoing debate about climate change and the impact of human activities, questions have been asked whether a further increase in the frequency and intensity of similar events might be expected in the near future."

In an attempt to provide a well-founded data-based answer to this important question, Bielec-Bakowska and Piotrowicz analyzed the frequency of occurrence of air pressure values equal to or lower than the 1st percentile (equivalent to $\leq$ 995.3 hPa) of all air pressure values recorded at 12:00 UTC in Krakow, Poland, over a period of 110 years (1900/1901-2009/2010), with "special attention" being devoted to the *tracks of deep cyclones*. This work revealed that the frequency of deep cyclones in Poland, both overall and in each of a number of specific track groups, "failed to change significantly" over the 110-year period of their study (see Figure 9 below). And in the most important of these groups, which was composed of "more than half of all deep cyclones," they found they "developed over the Atlantic and travelled over or near Iceland via the Baltic Sea and/or the Scandinavian Peninsula," and that "towards the end of the study period, it was observed that deep cyclones following these tracks shortened their journeys considerably," due to the fact that "as they moved over the Scandinavian Peninsula or the Baltic Sea, they 'suddenly' weakened and filled up."

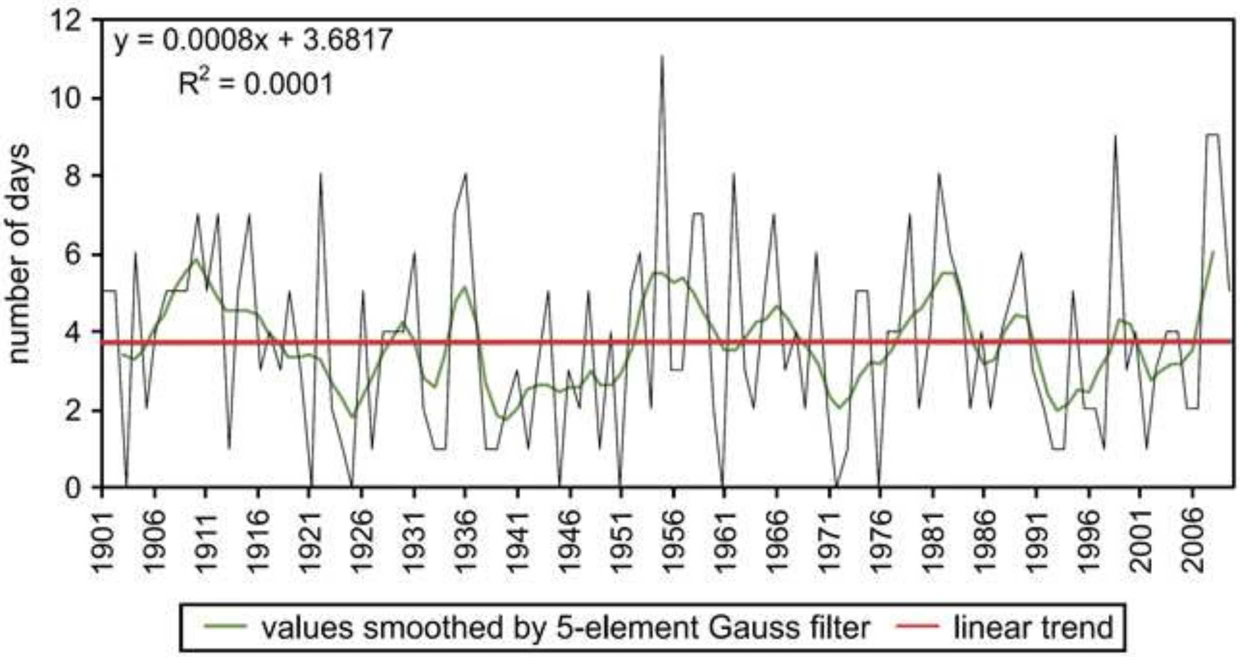

Figure 9. *Long-term variability of the number of days with deep cyclones (≤ 995.3 hPa) in Krakow, Poland over the period 1900-2010. Adapted from Bielec-Bakowska and Piotrowicz (2013).*

In the concluding paragraph of their paper, Bakowska and Piotrowicz thus wrote that their study "failed to clearly confirm any increase in the frequency of particularly deep cyclones," which *means*, as they noted, that "forecasts envisaging higher frequencies of strong winds accompanying deep cyclones must be treated with caution."

Using an historical hail dataset of 753 stations compiled by the National Meteorological Information Center of China, which "includes hail data for all weather stations in the surface meteorological observational network over the whole of China from 1951 to 2005," Xie *et al*. (2008) "chose 523 stations with complete observations from 1960 to 2005" to use in their study of "annual variations and trend[s] of hail frequency across mainland China during 1960-2005."

As is clearly evident in Figure 10, Xie *et al*. note that the results of their study "show no trend in the mean Annual Hail Days (AHD) from 1960 to [the] early 1980s but a significant decreasing trend afterwards," which latter downturn, it should be noted, was concomitant with the warming of the globe that the IPCC claims was unprecedented over the past one to two millennia, leading the three authors to conclude that global warming may actually imply "a possible reduction of hail occurrence."

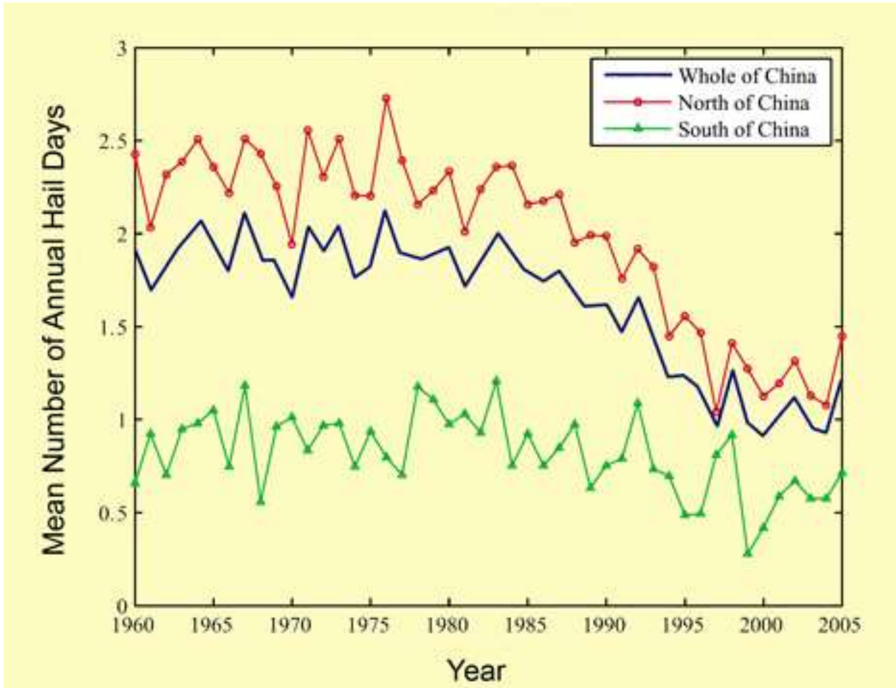

***Figure 10**. Mean Annual Hail Day variations and trends in northern China, southern China and the whole of China. Adapted from Xie et al. (2008).*

In another important study, Xie and Zhang (2010) set out to learn if there had been any change in another type of storm extremeness (hailstone size), noting that "changes in hail size are also an important aspect of hail climatology." Specifically, they examined the long-term trend of hail size in four regions of China over the period 1980-2005, using maximum hail diameter data obtained from the Meteorological Administrations of Xinjiang Uygur Autonomous Region (XUAR), Inner Mongolia Autonomous Region (IMAR), Guizhou Province and Hebei Province. The results of this study revealed an uptrend in maximum hail diameter in Hebei, a flat trend in XUAR, and a slight downtrend in both Guizhou and IMAR; but they add that "none of the trends is statistically significant." And in light of these several findings, it should be clear that the highly-hyped global warming of the past few decades has led to no increase in the extremeness of Chinese hail storms. In fact, the data suggest there was a slight decline in the frequency of such storms, along with a hint of a possible decrease in maximum hail diameter, which latter non-significant observation doesn't really mean very much, except that it strongly suggests there was at least no increase in maximum hail diameter.

Lastly, exploring global storm trends from another perspective, Gulev and Grigorieva (2004) analyzed ocean wave heights (a proxy for storms) using the Voluntary Observing Ship wave data of Worley *et al*. (2005) to characterize significant wave height (HS) over various ocean basins throughout all or parts of the 20th century. In doing so, the two Russian scientists found that "the annual mean HS visual time series in the northeastern Atlantic and northeastern Pacific show a pronounced increase of wave height starting from 1950," which finding sounds pretty much like it vindicates model projections of increasing storms. "However," as they continue, "for the period 1885-2002 there is no secular trend in HS in the Atlantic," and they note that "the upward trend in the Pacific for this period ... becomes considerably weaker than for the period 1885-2002."

Gulev and Grigorieva also note that the highest annual HS in the Pacific during the first half of the century "is comparable with that for recent decades," and that "in the Atlantic it is even higher than during the last 5 decades." In fact, in the Atlantic the mean HS of the entire decade of the 1920s is higher than any recent decade; and the mean HS of the last half of the 1940s is also higher than the last five years of the record. In the Pacific it also appears the mean HS from the late 1930s to the late 1940s may have been higher than that of the last decade of the record, although there is a data gap right in the middle of this period that precludes a definitive answer on this latter point. Nevertheless, it is clear that annual mean wave height (a proxy for storminess) over the last decade of the 20th century – when the IPCC claims global temperatures were warmer than at any other time in the past one to two millennia – was *not* higher than annual wave height values that occurred earlier in the century.

The results of the studies described above indicate there has been little to no significant increase in either the frequency or intensity of stormy weather over the past several decades. In fact, most studies suggest that just the *opposite* has likely occurred. And similar findings are noted when expanding the scope of analysis to cover longer periods of time, as illustrated in the studies described below.

Starting in Australia, Alexander *et al*. (2011) introduce their study by stating that "understanding the long-term variability of storm activity would give a much better perspective on how unusual recent climate variations have been," and they note in this regard that "for southeast and eastern Australia some studies have been able to assess measures of storm activity over longer periods back to the 19th century (e.g., Alexander and Power, 2009; Rakich *et al*., 2008), finding either a decline in the number of storms or reduction in the strength of zonal geostrophic wind flow," although noting that these studies "were limited to the analysis of only one or two locations." Therefore, in an effort designed to significantly expand the database employed in their newest study of the subject, Alexander *et al*. analyzed storminess across the whole of southeast (SE) Australia using extreme (standardized seasonal 95th and 99th percentiles) geostrophic winds deduced from eight widespread stations possessing sub-daily atmospheric pressure observations dating back to the late 19th century.

Based on this endeavor, the four researchers found "strong evidence for a significant reduction in intense wind events across SE Australia over the past century." More specifically, they say "in nearly all regions and seasons, linear trends estimated for both storm indices over the period analyzed show a decrease," while "in terms of the regional average series," they say that "all seasons show statistically significant declines in both storm indices, with the largest reductions in storminess in autumn and winter." Thus, yet another paper illustrates that as the Earth warmed over the last century or more, the climate-alarmist prediction of CO_2-induced increases in global storminess is seen to be widely out of sync with reality.

Introducing their study of the subject, Dezileau *et al*. (2011) write, with respect to extreme weather events, that the major question of the day is: "are they linked to global warming or are they part of natural climate variability?" And in regard to the significance of this question, they say "it is essential to place such events in a broader context of time, and trace the history of climate changes over several centuries," because "these extreme events are inherently rare and therefore difficult to observe in the period of a human life." Only then can claims of increased extreme weather events resulting from CO_2-induced global warming be properly evaluated; and Dezileau *et al*. proceed to do just that. More specifically, the nine researchers analyzed regional historical archives and sediment cores they extracted from two Gulf of Aigues-Mortes lagoons in the northwestern part of the occidental Mediterranean Sea for bio- and geo-indicators of past storm activities there, specifically assessing "the frequency and intensity of [extreme] events during the last 1,500 years," as well as "links between past climatic conditions and storm activities."

Their analysis shows evidence of four "catastrophic storms of category 3 intensity or more," which occurred at approximately AD 455, 1742, 1848 and 1893. And "taking into account text description of the 1742 storm," they conclude that it was "of category more than 4 in intensity," and that all four of the storms "can be called superstorms." In addition, Dezileau *et al*. make a point of noting that "the apparent increase in intense storms around 250 years ago lasts to about AD 1900," whereupon "intense meteorological activity seems to return to a quiescent interval after (i.e. during the 20th century AD)." And they add that, "interestingly, the two periods of most frequent superstorm strikes in the Aigues-Mortes Gulf (AD 455 and 1700-1900) coincide with two of the coldest periods in Europe during the late Holocene (Bond cycle 1 and the latter half of the Little Ice Age.)" As a result, the authors state that "extreme storm events are associated with a large cooling of Europe," and they calculate that the risk of such storms occurring during that cold period "was higher than today by a factor of 10," noting "if this regime came back today, the implications would be dramatic."

In another study, Ogrin (2007) presented "an overview of severe storms and a reconstruction of periods with their reiterative occurrence in sub-Mediterranean Slovenia in the warm half of the year during the so-called pre-instrumental period," based on "data gathered in secondary and tertiary historical sources." Speaking of "violent storms" and "the periods in which these phenomena were more frequent and reached, as to the costs of damage caused, the level of natural disasters or even catastrophes," Ogrin reports "the 17th and 18th centuries were undoubtedly such periods, particularly their first halves, when besides storms also some other weather-caused natural disasters occurred quite often, so that the inhabitants, who mainly depended on the self-subsistent agriculture, could not recover for several years after some consecutive severe rigors of the weather." In addition, he reports that "the frequency of violent storms in that time was comparable to the incidence towards the end of the 20th century."

Ogrin further writes that the late 20th-century increase in violent storms "is supposed to be a human-generated consequence of emitting greenhouse gasses and of the resulting global warming of the atmosphere." However, in light of his findings, he reports that "the damage done by severe storms in the past does not differ significantly from the damage in the present." And this fact suggests that the weather extremes of today, which he says are "supposed to be a human-generated consequence of emitting greenhouse gasses and of the resulting global warming of the atmosphere," may well be caused by something else; for if they have occurred in the past for a different reason (and they have), they can be occurring today for a different reason too.

Finally, introducing their study, Barring and Fortuniak (2009) say that "extra-tropical cyclone frequency and intensity are currently under intense scrutiny because of the destruction recent windstorms have brought to Europe," adding that "several studies using reanalysis data covering the second half of the 20th century suggest increasing storm intensity in the northeastern Atlantic and European sector." Against this backdrop, Barring and Fortuniak analyzed the "inter-decadal variability in cyclone activity over northwestern Europe back to AD 1780 by combining information from eight storminess indices applied in a Eulerian framework," which indices "use the series of thrice-daily sea level pressure observations at Lund and Stockholm."

The two Swedish scientists say their results show that former reanalysis studies "cover a time period chiefly coinciding with a marked, but not exceptional in our 225-year perspective, positive variation in the regional cyclone activity that has more recently reversed," noting that "because of the inter-decadal variations, a near-centennial time perspective is needed when analyzing variations in extra-tropical cyclone activity and the associated weather conditions over northwestern Europe." And by taking this more proper approach, the two researchers found that (1) "there is no significant overall long-term trend common to all indices in cyclone activity in the North Atlantic and European region since the Dalton minimum," that (2) "the marked positive trend beginning around 1960 ended in the mid-1990s and has since then reversed," and that (3) "this positive trend was more an effect of a 20th-century minimum in cyclone activity around 1960, rather than extraordinary high values in [the] 1990s."

Viewed together, the studies discussed above, based on empirical observations, suggest there is no data-based reason to accept the climate-alarmist contention that storms will become either more frequent or more intense if the world warms a bit more in the future.

4. Concluding Remarks

The public debate over the potential consequences of rising atmospheric CO_2 on Earth's climate and biosphere has shifted over the years. First, the focus was squarely on temperature (global warming). Next came climate change, which shifted attention to multiple climatic indices that might be affected by the ongoing rise in the air's CO_2 content. More recently, the debate has coalesced around concerns that rising CO_2 might be impacting extreme weather, with many people claiming that the frequency and intensity of disaster-prone extreme weather events will increase. All too often, however, these latter claims have failed to stand up to scientific scrutiny, because they were made with little regard to following the principles of the scientific method.

As discussed in this report, key steps must be taken to ensure scientific legitimacy when making and testing claims about a possible CO_2-induced influence on extreme weather events. Without following these steps, it is impossible to confirm any impact of CO_2 on extreme weather over the past few decades. When such steps are followed, however, as illustrated by the large literature reviews herein, it is nearly impossible to *not* conclude that extreme weather events remain unaffected by CO_2-induced global warming—at least in the manner projected by the models. Quite to the contrary, observational data often indicate just the *opposite*, that many types of extreme weather events have become less frequent and less severe as the air's temperature and CO_2 concentration increased over the past half-century or more.

Those promoting the notion that floods, droughts, and/or storms are increasing because of CO_2-induced global warming are ignoring the rigors of scientific inquiry and analysis. It is false to assert that these extreme weather events are getting worse; and it is wrong to assert that they will worsen in the future if carbon dioxide emissions are not reduced. The data simply do not support such claims.

References

Alexander, L.V. and Power, S. 2009. Severe storms inferred from 150 years of sub-daily pressure observations along Victoria's 'Shipwreck Coast." *Australian Meteorological and Oceanographic Journal* **58**: 129-133.

Alexander, L.V., Tett, S.F.B. and Jonsson, T. 2005. Recent observed changes in severe storms over the United Kingdom and Iceland. *Geophysical Research Letters* **32**: 10.1029/2005GL022371.

Alexander. L.V., Wang, X.L., Wan, H. and Trewin, B. 2011. Significant decline in storminess over southeast Australia since the late 19th century. *Australian Meteorological and Oceanographic Journal* **61**: 23-30.

Allan, R., Tett, S. and Alexander, L. 2009. Fluctuations in autumn-winter severe storms over the British Isles: 1920 to present. *International Journal of Climatology* **29**: 357-371.

Allen, E.B., Rittenour, T.M., DeRose, R.J., Bekker, M.F., Kjelgren, R. and Buckley, B.M. 2013. A tree-ring based reconstruction of Logan River streamflow, northern Utah. *Water Resources Research* **49**: 8579-8588.

Andreadis, K.M., Clark, E.A., Wood, A.W., Hamlet, A.F. and Lettenmaier, D.P. 2005. Twentieth-century drought in the conterminous United States. *Journal of Hydrometeorology* **6**: 985-1001.

Andreadis, K.M. and Lettenmaier, D.P. 2006. Trends in 20th century drought over the continental United States. *Geophysical Research Letters* **33**: 10.1029/2006GL025711.

Arnaud, F., Revel, M., Chapron, E., Desmet, M. and Tribovillard, N. 2005. 7200 years of Rhone river flooding activity in Lake Le Bourget, France: a high-resolution sediment record of NW Alps hydrology. *The Holocene* **15**: 420-428.

Arnell, N. and Liu, C. 2001. Hydrology and water resources. In: McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. and White, K.S. (Eds.), *Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom.

Barnett, T., Malone, R., Pennell, W., Stammer, D., Semtner, B. and Washington, W. 2004. The effects of climate change on water resources in the West: Introduction and overview. *Climatic Change* **62**: 1-11.

Barnett, T.P. and Pierce, D.W. 2009. Sustainable water deliveries from the Colorado River in a changing climate. *Proceedings of the National Academy of Sciences USA* **106**: 7334-7338.

Barredo, J.I. 2009. Normalized flood losses in Europe: 1970-2006. *Natural Hazards and Earth System Sciences* **9**: 97-104.

Barredo, J.I. 2010. No upward trend in normalized windstorm losses in Europe: 1970-2008. *Natural Hazards and Earth System Sciences* **10**: 97-104.

Barredo, J.I., Sauri, D. and Llasat, M.C. 2012. Assessing trends in insured losses from floods in Spain 1971-2008. *Natural Hazards and Earth System Sciences* **12**: 1723-1729.

Barriendos, M. and Martin Vide, J. 1998. Secular climatic oscillations as indicated by catastrophic floods in the Spanish Mediterranean coastal area (14th-19th centuries). *Climatic Change* **38**: 473-491.

Barring, L. and Fortuniak, K. 2009. Multi-indices analysis of southern Scandinavian storminess 1780-2005 and links to interdecadal variations in the NW Europe-North Sea region. *International Journal of Climatology* **29**: 373-384.

Barring, L. and von Storch, H. 2004. Scandinavian storminess since about 1800. *Geophysical Research Letters* **31**: 10.1029/2004GL020441.

Battipaglia, G., Frank, D.C., Buntgen, U., Dobrovolny, P., Brazdil, R., Pfister, C. and Esper, J. 2010. Five centuries of Central European temperature extremes reconstructed from tree-ring density and documentary evidence. *Global and Planetary Change* **72**: 182-191.

Belotti, P., Caputo, C., Davoli, L., Evangelista, S., Garzanti, E., Pugliese, F. and Valeri, P. 2004. Morpho-sedimentary characteristics and Holocene evolution of the emergent part of the Ombrone River delta (southern Tuscany). *Geomorphology* **61**: 71-90.

Benito, G., Diez-Herrero, A. and de Villalta, M. 2003. Magnitude and frequency of flooding in the Tagus river (Central Spain) over the last millennium. *Climatic Change* **58**: 171-192.

Benito, G., Machado, M.J. and Perez-Gonzalez, A. 1996. Climate change and flood sensitivity in Spain. *Geological Society Special Publication* **115**: 85-98.

Benito, G., Rico, M., Sanchez-Moya, Y., Sopena, A., Thorndycraft, V.R. and Barriendos, M. 2010. The impact of late Holocene climatic variability and land use change on the flood hydrology of the Guadalentin River, southeast Spain. *Global and Planetary Change* **70**: 53-63.

Bergeron, Y. 1998. Les consequences des changements climatiques sur la frequence des feux et la composition forestiere au sud-ouest de la foret boreale quebecoise. *Geogr. Phy. Quaternary* **52**: 167-173.

Bergeron, Y. 2000. Species and stand dynamics in the mixed woods of Quebec's boreal forest. *Ecology* **81**: 1500-1516.

Bergeron, Y. and Archambault, S. 1993. Decreasing frequency of forest fires in the southern boreal zone of Quebec and its relation to global warming since the end of the 'Little Ice Age'. *The Holocene* **3**: 255-259.

Bergeron, Y., Gauthier, S., Kafka, V., Lefort, P. and Lesieur, D. 2001. Natural fire frequency for the eastern Canadian boreal forest: consequences for sustainable forestry. *Canadian Journal of Forest Research* **31**: 384-391.

Bering Ovesen, N., Legard Iversen, H., Larsen, S., Muller-Wohlfeil, D.I. and Svendsen, L. 2000. *Afstromningsforhold i Danske Vandlob*. Faglig rapport fra DMU, no. 340. Miljo-og Energiministeriet. Danmarks Miljoundersogelser, Silkeborg, Denmark.

Berkelhammer, M., Sinha, A., Mudelsee, M., and Cannariato, K.G. 2010. Persistent multidecadal power in the Indian summer monsoon. *Earth and Planetary Science Letters* **290**: 166-172.

Bielec-Bakowska, Z. and Piotrowicz, K. 2013. Long-term occurrence, variability and tracks of deep cyclones over Krakow (Central Europe) during the period 1900-2010. *International Journal of Climatology* **33**: 677-689.

Bond, G., Kromer, B., Beer, J., Muscheler, R., Evans, M.N., Showers, W., Hoffmann, S., Lotti-Bond, R., Hajdas, I. and Bonani, G. 2001. Persistent solar influence on North Atlantic climate during the Holocene. *Science* **294**: 2130-2136.

Bond, G., Showers, W., Cheseby, M., Lotti, R., Almasi, P., deMenocal, P., Priore, P., Cullen, H., Hajdas, I. and Bonani, G. 1997. A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates. *Science* **278**: 1257-1266.

Borgaonkar, H.P., Sikdera, A.B., Rama, S. and Panta, G.B. 2010. El Niño and related monsoon drought signals in 523-year-long ring width records of teak (*Tectona grandis* L.F.) trees from south India. *Palaeogeography, Palaeoclimatology, Palaeoecology* **285**: 74-84.

Bormann, H. 2010. Changing runoff regimes of German rivers due to climate change. *Erdkunde* **64**: 257-279.

Bormann, H., Pinter, N. and Elfert, S. 2011. Hydrological signatures of flood trends on German rivers: Flood frequencies, flood heights and specific stages. *Journal of Hydrology* **404**: 50-66.

Braun, H., Christl, M., Rahmstorf, S., Ganopolski, A., Mangini, A., Kubatzki, C., Roth, K. and Kromer, B. 2005. Possible solar origin of the 1,470-year glacial climate cycle demonstrated in a coupled model. *Nature* **438**: 208-211.

Briffa, K.R., Jones, P.D. and Hulme, M. 1994. Summer moisture variability across Europe, 1892-1991: An analysis based on the Palmer Drought Severity Index. *International Journal of Climatology* **14**: 475-506.

Buckley, B.M., Anchukaitis, K.J., Penny, D., Fletcher, R., Cook, E.R., Sano, M., Nam, L.C., Wichienkeeo, A., Minh, T.T. and Hong, T.M. 2010. Climate as a contributing factor in the demise of Angkor, Cambodia. *Proceedings of the National Academy of Sciences USA* **107**: 6748-6752.

Buckley, B.M., Palakit, K., Duangsathaporn, K., Sanguantham, P. and Prasomsin, P. 2007. Decadal scale droughts over northwestern Thailand over the past 448 years: links to the tropical Pacific and Indian Ocean sectors. *Climate Dynamics* **29**: 63-71.

Buntgen, U., Brazdil, R., Heussner, K.-U., Hofmann, J., Kontic, R., Kyncl, T., Pfister, C., Chroma, K. and Tegel, W. 2011. Combined dendro-documentary evidence of Central European hydroclimatic springtime extremes over the last millennium. *Quaternary Science Reviews* **30**: 3947-3959.

Burger, K., Seidel, J., Glasser, R., Sudhaus, D., Dostal, P. and Mayer, H. 2007. Extreme floods of the 19th century in southwest Germany. *La Houille Blanche*: 10.1051/lhb:2007008.

Butvilovskii, V.V. 1993. *Paleogeography of the Late Glacial and Holocene on Altai.* Tomsk University, Tomsk.

Byun, H.R. and Wilhite, D.A. 1999. Objective quantification of drought severity and duration. *Journal of Climate* **12**: 2747-2756.

Cai, Q., Liu, Y., Lei, Y., Bao, G. and Sun, B. 2014. Reconstruction of the March-August PDSI since 1703AD based on tree rings of Chinese pine (*Pinus tabulaeformis* Carr.) in the Lingkong Mountain, southeast Chinese loess Plateau. *Climate of the Past* **10**: 509-521, doi:10.5194/cp-10-509-2014.

Changnon, S.A. 2003. Geographical and temporal variations in thunderstorms in the contiguous United States during the 20th century. *Physical Geography* **24**: 138-152.

Changnon, S.A. and Changnon, D. 2006. A spatial and temporal analysis of damaging snowstorms in the United States. *Natural Hazards* **37**: 373-389.

Clarke, M., Rendell, H., Tastet, J-P., Clave, B. and Masse, L. 2002. Late-Holocene sand invasion and North Atlantic storminess along the Aquitaine Coast, southwest France. *The Holocene* **12**: 231-238.

Cleaveland, M.K., Stahle, D.W., Therrell, M.D., Villanueva-Diaz, J. and Burns, B.T. 2003. Tree-ring reconstructed winter precipitation and tropical teleconnections in Durango, Mexico. *Climatic Change* **59**: 369-388.

Cluis, D. and Laberge, C. 2001. Climate change and trend detection in selected rivers within the Asia-Pacific region. *Water International* **26**: 411-424.

Coeur, D. 2003. Genesis of a public policy for flood management in France: the case of the Grenoble valley (XVIIth-XIXth Centuries). In: Thorndycraft, V.R., Benito, G., Barriendos, M. and Llasat, M.C. (Eds.), *Palaeofloods, Historical Floods and Climatic Variability: Applications in Flood Risk Assessment*. CSIC, Madrid, Spain, pp. 373-378.

Cook, E.R., Seager, R., Cane, M.A. and Stahle, D.W. 2007. North American drought: reconstructions, causes, and consequences. *Earth Science Reviews* **81**: 93-134.

Cook, E.R., Seager, R., Heim Jr., R.R., Vose, R.S., Herweijer, C. and Woodhouse, C. 2010. Megadroughts in North America: placing IPCC projections of hydroclimatic change in a long-term palaeoclimate context. *Journal of Quaternary Science* **25**: 48-61.

Cook, E.R., Woodhouse, C., Eakin, C.M., Meko, D.M. and Stahle, D.W. 2004. Long-term aridity changes in the western United States. *Science* **306**: 1015-1018.

Crompton, R.P. and McAneney, K.J. 2008. Normalized Australian insured losses from meteorological hazards: 1967-2006. *Environmental Science and Policy* **11**: 371-378.

Cunderlik, J.M. and Ouarda, T.B.M.J. 2009. Trends in the timing and magnitude of floods in Canada. *Journal of Hydrology* **375**: 471-480.

Czymzik, M., Dulski, P., Plessen, B., von Grafinstein, U., Naumenn, R. and Brauer, A. 2010. A 450 year record of spring-summer flood layers in annually laminated sediments from Lake Ammersee (southern Germany). *Water Resources Research* **46**: 10.1029/2009WR008360.

Dai, A., Trenberth, K.E. and Qian, T. 2004. A global dataset of Palmer Drought Severity Index for 1870-2002: Relationship with soil moisture and effects of surface warming. *Journal of Hydrometeorology* **5**: 1117-1130.

Dando, W.A. 1980. *The Geography of Famine*. John Wiley, New York, New York, USA, p. 209.

Davi, N.K., Jacoby, G.C., Curtis, A.E. and Baatarbileg, N. 2006. Extension of drought records for central Asia using tree rings: West-Central Mongolia. *Journal of Climate* **19**: 288-299.

Dawson, A.G., Hickey, K., Holt, T., Elliott, L., Dawson, S., Foster, I.D.L., Wadhams, P., Jonsdottir, I., Wilkinson, J., McKenna, J., Davis, N.R. and Smith, D.E. 2002. Complex North Atlantic Oscillation (NAO) Index signal of historic North Atlantic storm-track changes. *The Holocene* **12**: 363-369.

Debret, M., Chapron, E., Desmet, M., Rolland-Revel, M., Magand, O., Trentesaux, A., Bout-Roumazeille, V., Nomade, J. and Arnaud, F. 2010. North western Alps Holocene paleohydrology recorded by flooding activity in Lake Le Bourget, France. *Quaternary Science Reviews* **29**: 2185-2200.

Denniston, R.F., DuPree, M., Dorale, J.A., Asmerom, Y., Polyak, V.J. and Carpenter, S.J. 2007. Episodes of late Holocene aridity recorded by stalagmites from Devil's Icebox Cave, central Missouri, USA. *Quaternary Research* **68**: 45-52.

Dezileau, L., Sabatier, P., Blanchemanche, P., Joly, B., Swingedouw, D., Cassou, C., Castaings, J., Martinez, P. and Von Grafenstein, U. 2011. Intense storm activity during the Little Ice Age on the French Mediterranean coast. *Palaeogeography, Palaeoclimatology, Palaeoecology* **299**: 289-297.

Diaz, S.C., Therrell, M.D., Stahle, D.W. and Cleaveland, M.K. 2002. Chihuahua (Mexico) winter-spring precipitation reconstructed from tree-rings, 1647-1992. *Climate Research* **22**: 237-244.

Douglas, E.M., Vogel, R.M. and Kroll, C.N. 2000. Trends in floods and low flows in the United States: impact of spatial correlation. *Journal of Hydrology* **240**: 90-105.

Douglass, A.E. 1929. The secret of the Southwest solved with talkative tree rings. *National Geographic* **December**: 736-770.

Douglass, A.E. 1935. Dating Pueblo Bonito and other ruins of the Southwest. National Geographic Society Contributed Technical Papers. *Pueblo Bonito Series* **1**: 1-74.

Ducic, V. 2005. Reconstruction of the Danube discharge on hydrological station Orsova in pre-instrumental period: Possible causes of fluctuations. *Edition Physical Geography of Serbia* **2**: 79-100.

Ely, L.L. 1997. Response of extreme floods in the southwestern United States to climatic variations in the late Holocene. *Geomorphology* **19**: 175-201.

Emile-Geay, J., Cane, M., Seager, R., Kaplan, A. and Almasi, P. 2007. El Niño as a mediator of the solar influence on climate. *Paleoceanography* **22**: 10.1029/2006PA001304.

Esper, J., Frank, D., Buntgen, U., Verstege, A., Luterbacher, J. and Xoplaki, E. 2007. Long-term drought severity variations in Morocco. *Geophysical Research Letters* **34**: 10.1029/2007GL030844.

Forland, E., Roald, L.A., Tveito, O.E. and Hanssen-Bauer, I. 2000. *Past and Future Variations in Climate and Runoff in Norway*. DNMI Report no. 1900/00 KLIMA, Oslo, Norway.

Frank, D.C., Esper, J., Raible, C.C., Buntgen, U., Trouet, V., Joos, F. and Stocker, B. 2010. Ensemble reconstruction constraints of the global carbon cycle sensitivity to climate. *Nature* **463**: 527-530.

Fye, F.K., Stahle, D.W. and Cook, E.R. 2003. Paleoclimatic analogs to twentieth-century moisture regimes across the United States. *Bulletin of the American Meteorological Society* **84**: 901-909.

Garbrecht, J.D. and Rossel, F.E. 2002. Decade-scale precipitation increase in Great Plains at end of 20th century. *Journal of Hydrologic Engineering* **7**: 64-75.

Gaume, E., Bain, V., Bernardara, P., Newinger, O., Barbuc, M., Bateman, A., Blaskovicova, L., Bloschl, G., Borga, M., Dumitrescu, A., Daliakopoulos, I., Garcia, J., Irimescu, A., Kohnova, S., Koutroulis, A., Marchi, L., Matreata, S., Medina, V., Preciso, E., Sempere-Torres, D., Stancalie, G., Szolgay, J., Tsanis, I., Velasco, D. and Viglione, A. 2009. A compilation of data on European flash floods. *Journal of Hydrology* **367**: 70-78.

Gedalof, Z., Peterson, D.L. and Mantua, N.J. 2004. Columbia River flow and drought since 1750. *Journal of the American Water Resources Association* **40**: 1579-1592.

Gerstengarbe, F.-W. and Werner, P.C. 2008. Climate development in the last century -- global and regional. *International Journal of Medical Microbiology* **298**: 5-11.

Giorgi, F. and Lionello, P. 2008. Climate change projections for the Mediterranean region. *Global and Planetary Change* **63**: 90-104.

Girardin, M-P., Tardif, J., Flannigan, M.D. and Bergeron, Y. 2004. Multicentury reconstruction of the Canadian Drought Code from eastern Canada and its relationship with paleoclimatic indices of atmospheric circulation. *Climate Dynamics* **23**: 99-115.

Giraudi, C. 2005. Late-Holocene alluvial events in the Central Apennines, Italy. *The Holocene* **15**: 768-773.

Glueck, M.F. and Stockton, C.W. 2001. Reconstruction of the North Atlantic Oscillation, 1429-1983. *International Journal of Climatology* **21**: 1453-1465.

Glur, L., Wirth, S.B., Buntgen, U., Gilli, A., Haug, G.H., Schar, C., Beer, J. and Anselmetti, F.S. 2013. Frequent floods in the European Alps coincide with cooler periods of the past 2500 years. *Scientific Reports* **3**: 10.1038,srep02770.

Graumlich, L.J., Pisaric, M.F.J., Waggoner, L.A., Littell, J.S. and King, J.C. 2003. Upper Yellowstone River flow and teleconnections with Pacific Basin climate variability during the past three centuries. *Climatic Change* **59**: 245-262.

Gray, S.T., Betancourt, J.L., Fastie, C.L. and Jackson, S.T. 2003. Patterns and sources of multidecadal oscillations in drought-sensitive tree-ring records from the central and southern Rocky Mountains. *Geophysical Research Letters* **30**: 10.1029/2002GL016154.

Guilbert, X. 1994. Les crues de la Durance depuis le XIVeme siècle. Frequence, periodicite et interpretation paleo-climatique. *Memoire de maitrise de Geographie*. Universite d'Aix-Marseille I, Aix-en-Provence.

Gulev, S.K. and Grigorieva, V. 2004. Last century changes in ocean wind wave height from global visual wave data. *Geophysical Research Letters* **31**: 10.1029/2004GL021040.

Gulev, S.K., Zolina, O. and Grigoriev, S. 2001. Extratropical cyclone variability in the Northern Hemisphere winter from the NCEP/NCAR reanalysis data. *Climate Dynamics* **17**: 795-809.

Gutowski Jr., W.J., Hegerl, G.C., Holland, G.J., Knutson, T.R., Mearns, L.O., Stouffer, R.J., Webster, P.J., Wehner, M.F., Zwiers, F.W., Brooks, H,.E., Emanuel, K.A., Kormar, P.D., Kossin, J.P., Kunkel, K.E., McDnald, R., Meehl, G.A. and Trapp, R.J. 2008. Causes of observed changes in extremes and projections of future changes. In: Karl, T.R., Meehl, G.A., Miller, C.D., Hassol, S.J., Waple, A.M. and Murray, W.L. (Eds.). *Weather and Climate Extremes in a Changing Climate-Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands.* U.S. Climate Change Science, Washington, DC, USA.

Hage, K. 2003. On destructive Canadian prairie windstorms and severe winters. *Natural Hazards* **29**: 207-228.

Haque, C.E. 2000. Risk assessment, emergency preparedness and response to hazards: The case of the 1997 Red River Valley flood, Canada. *Natural Hazards* **21**: 225-245.

Hayden, B.P. 1999. Climate change and extratropical storminess in the United States: An assessment. *Journal of the American Water Resources Association* **35**: 1387-1397.

Hegerl, G., Luterbacher, J., Gonzalez-Rouco, F.J., Tett, S., Crowley, T. and Xoplaki, E. 2011. Influence of human and natural forcing on European seasonal temperatures. *Nature Geosciences* **4**: 99-103.

Herweijer, C., Seager, R. and Cook, E.R. 2006. North American droughts of the mid to late nineteenth century: a history, simulation and implication for Mediaeval drought. *The Holocene* **16**: 159-171.

Hirsch, R.M. and Ryberg, K.R. 2012. Has the magnitude of floods across the USA changed with global CO_2 levels? *Hydrological Sciences Journal* **57**: 10.1080/02626667.2011.621895.

Hisdal, H., Stahl, K., Tallaksen, L.M. and Demuth, S. 2001. Have streamflow droughts in Europe become more severe or frequent? *International Journal of Climatology* **21**: 317-333.

Hodell, D.A., Brenner, M., Curtis, J.H. and Guilderson, T. 2001. Solar forcing of drought frequency in the Maya lowlands. *Science* **292**: 1367-1369.

Hodell, D.A., Curtis, J. and Brenner, M. 1995. Possible role of climate in the collapse of classic Maya civilization. *Nature* **375**: 391-394.

Hofgaard, A., Tardif, J. and Bergeron, Y. 1999. Dendroclimatic response of *Picea mariana* and *Pinus banksiana* along a latitudinal gradient in the eastern Canadian boreal forest. *Canadian Journal of Forest Research* **29**: 1333-1346.

Holmes, J.A., Street-Perrott, F.A., Allen, M.J., Fothergill, P.A., Harkness, D.D., Droon, D. and Perrott, R.A. 1997. Holocene palaeolimnology of Kajemarum Oasis, Northern Nigeria: An isotopic study of ostracodes, bulk carbonate and organic carbon. *Journal of the Geological Society, London* **154**: 311-319.

Hyvarinen, V. 2003. Trends and characteristics of hydrological time series in Finland. *Nordic Hydrology* **34**: 71-90.

Idso, C.D., Carter, R.M. and Singer, S.F. (Eds.) 2013. *Climate Change Reconsidered II: Physical Science*. The Heartland Institute, Chicago, Illinois.

Indrapala, K. 1971. *The Collapse of the Rajarata Civilization and the Drift to the Southwest*. University of Ceylon Press.

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate Change 2007: The Physical Science Basis. Solomon, S., Qin, D., Manniing, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (Eds.). *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom.

Jacoby, G.C., D'Arrigo, R.D. and Davaajatms, T. 1996. Mongolian tree rings and 20th century warming. *Science* **273**: 771-773.

Jiang, T., Zhang, Q., Blender, R. and Fraedrich, K. 2005. Yangtze Delta floods and droughts of the last millennium: Abrupt changes and long term memory. *Theoretical and Applied Climatology* **82**: 131-141.

Jylha, K., Tuomenvirta, H. and Ruosteenoja, K. 2004. Climate change projections in Finland during the 21st century. *Boreal Environmental Research* **9**: 127-152.

Kalugin, I., Selegei, V., Goldberg, E. and Seret, G. 2005. Rhythmic fine-grained sediment deposition in Lake Teletskoye, Altai, Siberia, in relation to regional climate change. *Quaternary International* **136**: 5-13.

Kim, D.-W., Byun, H.-R. and Choi, K.-S. 2009. Evaluation, modification, and application of the Effective Drought Index to 200-Year drought climatology of Seoul, Korea. *Journal of Hydrology* **378**: 1-12.

Klavins, M., Briede, A., Rodinov, V., Kokorite, I. and Frisk, T. 2002. Long-term changes of the river runoff in Latvia. *Boreal Environmental Research* **7**: 447-456.

Knox, J.C. 2001. Agricultural influence on landscape sensitivity in the Upper Mississippi River Valley. *Catena* **42**: 193-224.

Kondrashov, D., Feliks, Y. and Ghil, M. 2005. Oscillatory modes of extended Nile River records (A.D. 622-1922). *Geophysical Research Letters* **32**: doi:10.1029/2004GL022156.

Korhonen, J. and Kuusisto, E. 2010. Long-term changes in the discharge regime in Finland. *Hydrology Research* **41**: 253-268.

Kundzewicz, Z.W., Kanae, S., Seneviratne, S.I., Handmer, J., Nicholls, N., Peduzzi, P., Mechler, R., Bouwer, L.M., Arnell, N., Mach, K., Muir-Wood, R., Brakenridge, G.R., Kron, W., Benito, G., Honda, Y., Takahashi, K. and Sherstyukov, B. 2014. Flood risk and climate change: global and regional perspectives. *Hydrological Sciences Journal* **59**: 1-28.

Kundzewicz, Z.W., Ulbrich, U., Brucher, T., Graczyk, D., Kruger, A., Leckebusch, G.C., Menzel, L., Pinskwar, I., Radziejewski, M. and Szwed, M. 2005. Summer floods in Central Europe - climate change track? *Natural Hazards* **36**: 165-189.

Lawson, B.D. 2003. Trends in blizzards at selected locations on the Canadian prairies. *Natural Hazards* **29**: 123-138.

Liang, E.Y., Liu, X.H., Yuan, Y.J., Qin, N.S., Fang, X.Q., Huang, L., Zhu, H.F., Wang, L.L. and Shao, X.M. 2006. The 1920s drought recorded by tree rings and historical documents in the semi-arid and arid areas of northern China. *Climatic Change* **79**: 403-432.

Linderholm, H.W. and Chen, D. 2005. Central Scandinavian winter precipitation variability during the past five centuries reconstructed from *Pinus sylvestris* tree rings. *Boreas* **34**: 44-52.

Linderholm, H.W. and Molin, T. 2005. Early nineteenth century drought in east central Sweden inferred from dendrochronological and historical archives. *Climate Research* **29**: 63-72.

Lindstrom, G. and Bergstrom, S. 2004. Runoff trends in Sweden 1807-2002. *Hydrological Sciences Journal* **49**: 69-83.

Lins, H.F. and Slack, J.R. 1999. Streamflow trends in the United States. *Geophysical Research Letters* **26**: 227-230.

Llasat, M.-C., Barriendos, M., Barrera, A. and Rigo, T. 2005. Floods in Catalonia (NE Spain) since the 14th century. Climatological and meteorological aspects from historical documentary sources and old instrumental records. *Journal of Hydrology* **313**: 32-47.

Luterbacher, J., *et al*. 2006. Mediterranean climate variability over the last centuries: A review. In: Lionello, P., *et al*., Eds. *The Mediterranean Climate*, Elsevier, Amsterdam, The Netherlands, pp. 27-148.

Ma, S. 1958. The population dynamics of the oriental migratory locust (*Locusta migratoria manilensis* Meyen) in China. *Acta Entomologica Sinica* **8**: 1-40.

MacDonald, G.M., Kremenetski, K.V. and Hidalgo, H.G. 2008. Southern California and the perfect drought: Simultaneous prolonged drought in Southern California and the Sacramento and Colorado River systems. *Quaternary International* **188**: 11-23.

MacDonald, G.M. and Tingstad, A.H. 2007. Recent and multicentennial precipitation variability and drought occurrence in the Uinta Mountains region, Utah. *Arctic, Antarctic, and Alpine Research* **39**: 549-555.

Maharatna, A. 1996. The Demography of Famines: An Indian Historical Perspective. Oxford University Press, Delhi, India, p. 317.

Mann, M.E., Bradley, R.S. and Hughes, M.K. 1999. Northern Hemisphere temperatures during the past millennium: Inferences, uncertainties, and limitations. *Geophysical Research Letters* **26**: 759-762.

Mann, M.E. and Jones, P.D. 2003. Global surface temperatures over the past two millennia. *Geophysical Research Letters* **30**: 10.1029/2003GL017814.

Marengo, J.A. 1992. Interannual variability of surface climate in the Amazon basin. *International Journal of Climatology* **12**: 853-863.

Marengo, J.A. 2004. Interdecadal and long term rainfall variability in the Amazon basin. *Theoretical and Applied Climatology* **78**: 79-96.

Marengo, J.A. 2009. Long-term trends and cycles in the hydrometeorology of the Amazon basin since the late 1920s. *Hydrological Processes* **23**: 3236-3244.

Marengo, J. and Hastenrath, S. 1993. Case studies of extreme climatic events in the Amazon basin. *Journal of Climate* **6**: 617-627.

Masiokas, M.H., Villalba, R., Christie, D.A., Betman, E., Luckman, B.H., Le Quesne, C., Prieto, M.R. and Mauget, S. 2012. Snowpack variations since AD 1150 in the Andes of Chile and Argentina (30°-37°S) inferred from rainfall, tree-ring and documentary records. *Journal of Geophysical Research* **117**: 10.1029/2011JD016748.

McCabe, G.J. and Wolock, D.M. 2002. A step increase in streamflow in the conterminous United States. *Geophysical Research Letters* **29**: 2185-2188.

Meko, D.M., Woodhouse, C.A., Baisan, C.A., Knight, T., Lukas, J.J., Hughes, M.K. and Salzer, M.W. 2007. Medieval drought in the upper Colorado River Basin. *Geophysical Research Letters* **34**: 10.1029/2007GL029988.

Minetti, J.L., Vargas, W.M., Poblete, A.G., de la Zerda, L.R. and Acuña, L.R. 2010. Regional droughts in southern South America. *Theoretical and Applied Climatology* **102**: 403-415.

Miramont, C., Jorda, M. and Pichard, G. 1998. Evolution historique de la morphogenese et de la dynamique fluviale d'une riviere mediterraneenne: l'exemple de la moyenne Durance (France du sud-est). *Geographie physique et Quatenaire* **52**: 381-392.

Mitchell, T.D., Carter, T.R., Jones, P.D., Hulme, M. and New, M. 2004. *A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: The observed record (1901-2000) and 16 scenarios (2001-2100)*. Tyndall Center Working Paper 55, Norwich, UK.

Molnar, P. and Ramirez, J.A. 2001. Recent trends in precipitation and streamflow in the Rio Puerco Basin. *Journal of Climate* **14**: 2317-2328.

Moreno, A., Valero-Garces, B., Gonzales-Samperiz, P. and Rico, M. 2008. Flood response to rainfall variability during the last 2000 years inferred from the Taravilla Lake record (Central Iberian Range, Spain). *Journal of Paleolimnology* **40**: 943-961.

Mudelsee, M., Borngen, M., Tetzlaff, G. and Grunewald, U. 2003. No upward trends in the occurrence of extreme floods in central Europe. *Nature* **425**: 166-169.

Mudelsee, M., Borngen, M., Tetzlaff, G. and Grunewald, U. 2004. Extreme floods in central Europe over the past 500 years: Role of cyclone pathway "Zugstrasse Vb." *Journal of Geophysical Research* **109**: 10.1029/2004JD005034.

Mudelsee, M., Deutsch, M., Borngen, M. and Tetzlaff, G. 2006. Trends in flood risk of the river Werra (Germany) over the past 500 years. *Hydrological Sciences Journal* **51**: 818-833.

Mundo, I.A., Masiokas, M.H., Villalba, R., Morales, M.S., Neukom, R., Le Quesne, C., Urrutia, R.B. and Lara, A. 2012. Multi-century tree-ring based reconstruction of the Neuquen River streamflow, northern Patagonia, Argentina. *Climate of the Past* **8**: 815-829.

Narisma, G.T., Foley, J.A., Licker, R. and Ramankutty, N. 2007. Abrupt changes in rainfall during the twentieth century. *Geophysical Research Letters* **34**: 10.1029/2006GL028628.

Nash, D.J. and Endfield, G.H. 2002. A 19th-century climate chronology for the Kalahari region of central southern Africa derived from missionary correspondence. *International Journal of Climatology* **22**: 821-841.

Neumayer, E. and Barthel, F. 2011. Normalizing economic loss from natural disasters: A global analysis. *Global Environmental Change* **21**: 13-24.

Ogrin, D. 2007. Severe storms and their effects in sub-Mediterranean Slovenia from the 14th to the mid-19th century. *Acta Geographica Slovenia* **47**: 7-24.

Olsen, J.R., Stedinger, J.R., Matalas, N.C. and Stakhiv, E.Z. 1999. Climate variability and flood frequency estimation for the Upper Mississippi and Lower Missouri Rivers. *Journal of the American Water Resources Association* **35**: 1509-1523.

Pant, G.B., Rupa-Kumar, K.N., Sontakke, A. and Borgaonkar, H.P. 1993. Climate variability over India on century and longer time scales. In: Keshavamurty, R.N. and Joshi, P.C. (Eds.). *Tropical Meteorology*. Tata McGraw-Hill, New Delhi, India, pp. 149-158.

Panyushkina, I.P., Adamenko, M.F., Ovchinnikov, D.V. 2000. Dendroclimatic net over Altai Mountains as a base for numerical paleogeographic reconstruction of climate with high time resolution. In: *Problems of Climatic Reconstructions in Pleistocene and Holocene 2*. Institute of Archaeology and Ethnography, Novosibirsk, pp. 413-419.

Paulsen, D.E., Li, H.-C. and Ku, T.-L. 2003. Climate variability in central China over the last 1270 years revealed by high-resolution stalagmite records. *Quaternary Science Reviews* **22**: 691-701.

Petrow, T. and Merz, B. 2009. Trends in flood magnitude, frequency and seasonality in Germany in the period 1951-2002. *Journal of Hydrology* **371**: 129-141.

Pfister, C. 2005. Weeping in the snow. The second period of Little Ice Age-type impacts, 1570-1630. In: Behringer, W., Lehmann, H. and Pfister, C. (Eds.) *Kulturelle Konsequenzen der "Kleinen Eiszeit,"* Vandenhoeck, Gottingen, Germany, pp. 31-86.

Pfister, C., Weingartner, R. and Luterbacher, J. 2006. Hydrological winter droughts over the last 450 years in the Upper Rhine basin: a methodological approach. *Journal des Sciences Hydrologiques* **51**: 966-985.

Pielke Jr., R.A., Gratz, J., Landsea, C.W., Collins, D., Saunders, M.A. and Musulin, R. 2008. Normalized hurricane damage in the United States: 1900-2005. *Natural Hazards Review* **31**: 29-42.

Pielke Jr., R.A. and Landsea, C.W. 1998. Normalized hurricane damage in the United States: 1925-95. *Weather and Forecasting* **13**: 621-631.

Pinter, N., Jemberie, A.A., Remo, J.W.F., Heine, R.A. and Ickes, B.S. 2008. Flood trends and river engineering on the Mississippi River system. *Geophysical Research Letters* **35**: 10.1029/2008GL035987.

Quiring, S.M. 2004. Growing-season moisture variability in the eastern USA during the last 800 years. *Climate Research* **27**: 9-17.

Quiring, S.M. and Papakyriakou, T.N. 2005. Characterizing the spatial and temporal variability of June-July moisture conditions in the Canadian prairies. *International Journal of Climatology* **25**: 117-138.

Rakich, C.S., Holbrook, N.J. and Timbal, B. 2008. A pressure gradient metric capturing planetary-scale influences on eastern Australian rainfall. *Geophysical Research Letters* **35**: 10.1029/2007GL032970.

Raspopov, O.M., Dergachevb, V.A. and Kolström, T. 2004. Periodicity of climate conditions and solar variability derived from dendrochronological and other palaeo-climatic data in high latitudes. *Palaeogeography, Palaeoclimatology, Palaeoecology* **209**: 127-139.

Rauscher, A.A., Pal, J.S., Diffenbaugh, N.S. and Benedetti, M.M. 2008. Future changes in snowmelt-driven runoff timing over the western U.S. *Geophysical Research Letters* **35**: 10.1029/2008GL034424.

Renard, B., Lang, M., Bois, P., Dupeyrat, A., Mestre, O., Niel, H., Sauquet, E., Prudhomme, C., Parey, S., Paquet, E., Neppel. L. and Gailhard, J. 2008. Regional methods for trend detection: Assessing field significance and regional consistency. *Water Resources Research* **44**: 10.1029/2007WR006268.

Roald, L.A. 1999. *Analyse av Lange Flomserier*. HYDRA-rapport no. F01, NVE, Oslo, Norway.

Robock, A., Mu, M., Vinnikov, K., Trofimova, I.V. and Adamenko, T.I. 2005. Forty-five years of observed soil moisture in the Ukraine: No summer desiccation (yet). *Geophysical Research Letters* **32**: 10.1029/2004GL021914.

Robson, A.J., Jones, T.K., Reed, D.W. and Bayliss, A.C. 1998. A study of national trends and variation in UK floods. *International Journal of Climatology* **18**: 165-182.

Sano, M., Buckley, B.M. and Sweda, T. 2009. Tree-ring based hydroclimate reconstruction over northern Vietnam from *Fokienia hodginsii*: eighteenth century mega-drought and tropical Pacific influence. *Climate Dynamics* **33**: 331-340.

Sauchyn, D.J. and Skinner, W.R. 2001. A proxy record of drought severity for the southwestern Canadian plains. *Canadian Water Resources Journal* **26**: 253-272.

Sauchyn, D.J., Vanstone, J. and Perez-Valdivia, C. 2011. Modes and forcing of hydroclimatic variability in the upper North Saskatchewan River Basin since 1063. *Canadian Water Resources Journal* **36**: 205-218.

Schindler, D.W. and Donahue, W.F. 2006. An impending water crisis in Canada's western prairie provinces. *Proceedings of the National Academy of Sciences, USA* **103**: 7210-7216.

Schmocker-Fackel, P. and Naef, F. 2010. Changes in flood frequencies in Switzerland since 1500. *Hydrology and Earth System Sciences* **14**: 1581-1594.

Schonwiese, C.-D. 1999. Das Klima der jungeren Vergangenheit. *Physik in unserer Zeit* **30**: 94-101.

Seager, R. 2007. The turn of the century North American drought: Global context, dynamics, and past analogs. *Journal of Climate* **20**: 5527-5552.

Seager, R., Kushnir, Y., Herweijer, C., Naik, N. and Velez, J. 2005. Modeling of tropical forcing of persistent droughts and pluvials over western North America: 1856-2000. *Journal of Climate* **18**: 4068-4091.

Shapley, M.D., Johnson, W.C., Engstrom, D.R. and Osterkamp, W.R. 2005. Late-Holocene flooding and drought in the Northern Great Plains, USA, reconstructed from tree rings, lake sediments and ancient shorelines. *The Holocene* **15**: 29-41.

Sheffer, N.A. 2003. *Paleoflood Hydrology of the Ardeche River, France. A Contribution to Flood Risk Assessment.* M.Sc. Dissertation, The Hebrew University of Jerusalem, Israel.

Sheffer, N.A. 2005. Reconstructing the paleoclimate record using paleoflood hydrology as a proxy. *Fifth Conference on Active Research, CARESS 2005*. The Weitzmann Institute of Science, Rehovot, Israel.

Sheffer, N.A., Enzel, Y., Benito, G., Grodek, T., Porat, N., Lang, M., Naulet, R. and Coeur, D. 2003b. Paleofloods and historical floods of the Ardeche River, France. *Water Resources Research* **39**: 1376.

Sheffer, N.A., Enzel, Y., Grodek, T., Waldmann, N. and Benito, G. 2003a. Claim of largest flood on record proves false. *EOS: Transactions, American Geophysical Union* **84**: 109.

Sheffer, N.A., Rico, M., Enzel, Y., Benito, G. and Grodek, T. 2008. The palaeoflood record of the Gardon River, France: A comparison with the extreme 2002 flood event. *Geomorphology* **98**: 71-83.

Sheffield, J., Andreadis, K.M., Wood, E.F. and Lettenmaier, D.P. 2009. Global and continental drought in the second half of the twentieth century: severity-area-duration analysis and temporal variability of large-scale events. *Journal of Climate* **22**: 1962-1981.

Sinha, A., Cannariato, K.G., Stott, L.D., Cheng, H., Edwards, R.L., Yadava, M.G., Ramesh, R. and Singh, I.B. 2007. A 900-year (600 to 1500 A.D.) record of the Indian summer monsoon precipitation from the core monsoon zone of India. *Geophysical Research Letters* **34**: 10.1029/2007GL030431.

Sinha, A., Stott, L., Berkelhammer, M., Cheng, H., Edwards, R.L., Buckley, B., Aldenderfer, M. and Mudelsee, M. 2011. A global context for megadroughts in monsoon Asia during the past millennium. *Quaternary Science Reviews* **30**: 47-62.

Sonett, C.P., Finney, S.A. and Berger, A. 1990. The spectrum of radiocarbon. *Philosophical Transactions of the Royal Society of London A* **330**: 413-426.

Spencer, R.W. 2013. Statement to the Environment and Public Works Committee, 19 July 2013, Washington, DC, 13 p.

Springer, G.S., Rowe, H.D., Hardt, B., Edwards, R.L. and Cheng, H. 2008. Solar forcing of Holocene droughts in a stalagmite record from West Virginia in east-central North America. *Geophysical Research Letters* **35**: 10.1029/2008GL034971.

St. George, S. and Nielsen, E. 2002. Hydroclimatic change in southern Manitoba since A.D. 1409 inferred from tree rings. *Quaternary Research* **58**: 103-111.

Stahle, D.W., Fye, F.K., Cook, E.R. and Griffin, R.D. 2007. Tree-ring reconstructed megadroughts over North America since AD 1300. *Climatic Change* **83**: 133-149.

Stambaugh, M.C., Guyette, R.P., McMurry, E.R., Cook, E.R., Meko, D.M. and Lupo, A.R. 2011. Drought duration and frequency in the U.S. Corn Belt during the last millennium (AD 992-2004). *Agricultural and Forest Meteorology* **151**: 154-162.

Stewart, M.M., Grosjean, M., Kuglitsch, F.G., Nussbaumer, S.U. and von Gunten, L. 2011. Reconstructions of late Holocene paleofloods and glacier length changes in the Upper Engadine, Switzerland (ca. 1450 BC-AD 420). *Palaeogeography, Palaeoclimatology, Palaeoecology* **311**: 215-223.

Stine, S. 1994. Extreme and persistent drought in California and Patagonia during mediaeval time. *Nature* **369**: 546-549.

Svensson, C., Kundzewicz, Z.W. and Maurer, T. 2005. Trend detection in river flow series: 2. Flood and low-flow index series. *Hydrological Sciences Journal* **50**: 811-824.

Swierczynski, T., Brauer, A., Lauterbach, S., Martin-Puertas, C., Dulski, P., von Grafenstein, U. and Rohr, C. 2012. A 1600 yr seasonally resolved record of decadal-scale flood variability from the Austrian Pre-Alps. *Geology* **40**: 1047-1050.

Tardif, J. and Bergeron, Y. 1997. Ice-flood history reconstructed with tree-rings from the southern boreal forest limit, western Quebec. *The Holocene* **7**: 291-300.

Tardif, J. and Bergeron, Y. 1999. Population dynamics of *Fraxinus nigra* in response to flood-level variations, in northwestern Quebec. *Ecological Monographs* **69**: 107-125.

Therrell, M.D., Stahle, D.W., Ries, L.P. and Shugart, H.H. 2006b. Tree-ring reconstructed rainfall variability in Zimbabwe. *Climate Dynamics* **26**: 677-685.

Therrell, M.D., Stahle, D.W., Villanueva Diaz, J., Cornejo Oviedo, E.H. and Cleaveland, M.K. 2006a. Tree-ring reconstructed maize yield in central Mexico: 1474-2001. *Climatic Change* **74**: 493-504.

Thorndycraft, V.R. and Benito, G. 2006a. Late Holocene fluvial chronology of Spain: the role of climatic variability and human impact. *Catena* **66**: 34-41.

Thorndycraft, V.R. and Benito, G. 2006b. The Holocene fluvial chronology of Spain: evidence from a newly compiled radiocarbon database. *Quaternary Science Reviews* **25**: 223-234.

Tian, J., Nelson, D.M. and Hu, F.S. 2006. Possible linkages of late-Holocene drought in the North American mid-continent to Pacific Decadal Oscillation and solar activity. *Geophysical Research Letters* **33**: 10.1029/2006GL028169.

Timilsena, J., Piechota, T.C., Hidalgo, H. and Tootle, G. 2007. Five hundred years of drought in the upper Colorado River basin. *Journal of the American Water Resources Association* **43**: 798-812.

Trenberth, K.E. 1999. Conceptual framework for changes of extremes of the hydrological cycle with climate change. *Climatic Change* **42**: 327-339.

Trenberth, K.E. and Owen, T. 1999. Workshop on indices and indicators for climate extremes: Breakout group A: Storms. *Climatic Change* **42**: 9-21.

Van der Schrier, G., Briffa, K.R., Osborn, T.J. and Cook, E.R. 2006. Summer moisture availability across North America. *Journal of Geophysical Research* **111**: 10.1029/2005JD006745.

Viau, A.E., Gajewski, K., Fines, P., Atkinson, D.E. and Sawada, M.C. 2002. Widespread evidence of 1500 yr climate variability in North America during the past 14,000 yr. *Geology* **30**: 455-458.

Villarini, G., Serinaldi, F., Smith, J.A. and Krajewski, W.F. 2009. On the stationarity of annual flood peaks in the continental United States during the 20th century. *Water Resources Research* **45**: 10.1029/2008WR007645.

Villarini, G. and Smith, J.A. 2010. Flood peak distributions for the eastern United States. *Water Resources Research* **46**: 10.1029/2009WR008395.

Villarini, G., Smith, J.A., Baeck, M.L. and Krajewski, W.F. 2011. Examining flood frequency distributions in the Midwest U.S. *Journal of the American Water Resources Association* **47**: 447-463.

Vorosmarty, C.J. 2002. Global change, the water cycle, and our search for Mauna Loa. *Hydrological Processes* **16**: 135-139.

Wang, Y. 2006. The preliminary study on the natural disaster in north Shaanxi during 1923-1931. *Meteorology and Disaster Reduction Research* **29**: 34-38.

Watson, T.A., Barnett, F.A., Gray, S.T. and Tootle, G.A. 2009. Reconstructed streamflows for the headwaters of the Wind River, Wyoming, United States. *Journal of the American Water Resources Association* **45**: 1536-1554.

Weakly, H.E. 1965. Recurrence of drought in the Great Plains during the last 700 years. *Agricultural Engineering* **46**: 85.

Webster, J.W., Brook, G.A., Railsback, L.B., Cheng, H., Edwards, R.L., Alexander, C. and Reeder, P.P. 2007. Stalagmite evidence from Belize indicating significant droughts at the time of Preclassic Abandonment, the Maya Hiatus, and the Classic Maya collapse. *Palaeogeography, Palaeoclimatology, Palaeoecology* **250**: 1-17.

Wells, N., Goddard, S. and Hayes, M.J. 2004. A self-calibrating Palmer drought severity index. *Journal of Climate* **17**: 2335-2351.

Wheaton, E., Kulshreshtha, S., Wittrock, V. and Koshida, G. 2008. Dry times: hard lessons from the Canadian drought of 2001 and 2002. *Canadian Geographer* **52**: 241-262.

Wilhelm, B., Arnaud, F., Sabatier, P., Crouzet, C., Brisset, E., Chaumillon, E., Disnar, J.-R., Guiter, F., Malet, E., Reyss, J.-L., Tachikawa, K., Bard, E. and Delannoy, J.-J. 2012. 1400 years of extreme precipitation patterns over the Mediterranean French Alps and possible forcing mechanisms. *Quaternary Research* **78**: 1-12.

Willard, D.A., Bernhardt, C.E., Korejwo, D.A. and Meyers, S.R. 2005. Impact of millennial-scale Holocene climate variability on eastern North American terrestrial ecosystems: pollen-based climatic reconstruction. *Global and Planetary Change* **47**: 17-35.

Wilson, R. J., Luckman, B. H. and Esper, J. 2005. A 500 year dendroclimatic reconstruction of spring-summer precipitation from the lower Bavarian Forest region, Germany. *International Journal of Climatology* **25**: 611-630.

Wise, E. 2010. Tree Ring record of streamflow and drought in the upper Snake River. *Water Resources Research* **46**: 10.1029/2010WR009282.

Wolfe, B.B., Karst-Riddoch, T.L., Vardy, S.R., Falcone, M.D., Hall, R.I. and Edwards, T.W.D. 2005. Impacts of climate and river flooding on the hydro-ecology of a floodplain basin, Peace-Athabasca Delta, Canada since A.D. 1700. *Quaternary Research* **64**: 147-162.

Woodhouse, C.A. 2004. A paleo perspective on hydroclimatic variability in the western United States. *Aquatic Sciences* **66**: 346-356.

Woodhouse, C.A. and Lukas, J.J. 2006. Multi-century tree-ring reconstructions of Colorado streamflow for water resource planning. *Climatic Change* **78**: 293-315.

Woodhouse, C.A., Gray, S.T. and Meko, D.M. 2006. Updated streamflow reconstructions for the Upper Colorado River Basin. *Water Resources Research* **42**: 10.1029/2005WR004455.

Woodhouse, C.A., Meko, D.M., MacDonald, G.M., Stahle, D.W. and Cook, E.R. 2010. A 1,200-year perspective of 21st century drought in southwestern North America. *Proceedings of the National Academy of Sciences USA* **107**: 21,283-21,288.

Woodhouse, C.A. and Overpeck, J.T. 1998. 2000 years of drought variability in the Central United States. *Bulletin of the American Meteorological Society* **79**: 2693-2714.

Worley, S.J., Woodruff, S.D., Reynolds, R.W., Lubker, S.J. and Lott, N. 2005. ICOADS release 2.1 data and products. *International Journal of Climatology* **25**: 823-842.

Xie, B. and Zhang, Q. 2010. Observed characteristics of hail size in four regions in China during 1980-2005. *Journal of Climate* **23**: 4973-4982.

Xie, B., Zhang, Q. and Wang, Y. 2008. Trends in hail in China during 1960-2005. *Geophysical Research Letters* **35**: 10.1029/2008GL034067.

Yang, B., Brauning, A., Johnson, K.R. and Yafeng, S. 2002. Temperature variation in China during the last two millennia. *Geophysical Research Letters* **29**: 10.1029/2001GL014485.

Zhang, K., Douglas, B.C. and Leatherman, S.P. 2000. Twentieth-Century storm activity along the U.S. East Coast. *Journal of Climate* **13**: 1748-1761.

Zhang, P.Z., Cheng, H., Edwards, R.L., Chen, F.H., Wang, Y.J., Yang, X.L., Liu, J., Tan, M., Wang, X.F., Liu, J.H., An, C.L., Dai, Z.B., Zhou, J., Zhang, D.Z., Jia, J.H., Jin, L.Y. and Johnson, K.R. 2008. A test of climate, sun, and culture relationships from an 1810-year Chinese cave record. *Science* **322**: 940-942.

Zhang, Q., Chen, J. and Becker, S. 2007. Flood/drought change of last millennium in the Yangtze Delta and its possible connections with Tibetan climatic changes. *Global and Planetary Change* **57**: 213-221.

Zhang, Q.-B. and Hebda, R.J. 2005. Abrupt climate change and variability in the past four millennia of the southern Vancouver Island, Canada. *Geophysical Research Letters* **32** L16708, doi:10.1029/2005GL022913.

Zhang, X., Harvey, K.D., Hogg, W.D. and Yuzyk, T.R. 2001. Trends in Canadian streamflow. *Water Resources Research* **37**: 987-998.

Zhang, Z., Cazelles, B., Tian, H., Stige, L.C., Brauning, A. and Stenseth, N.C. 2009. Periodic temperature-associated drought/flood drives locust plagues in China. *Proceedings of the Royal Society B* **276**: 823-831.

About the Center

The *Center for the Study of Carbon Dioxide and Global Change* was founded as a non-profit organization in 1998 to provide regular reviews and commentary on new developments in the world-wide scientific quest to determine the climatic and biological consequences of the ongoing rise in the air's CO_2 content. It achieves this objective primarily through the weekly online publication of '*CO_2 Science*,' which is freely available on the Internet at **www.co2science.org**, and contains reviews of recently published peer-reviewed scientific journal articles, original research, and other educational materials germane to the debate over carbon dioxide and global change.

The Center's main focus is to separate reality from rhetoric in the emotionally-charged debate that swirls around the subject of carbon dioxide and global change and to avoid the stigma of biased advocacy by utilizing sound science. It has a stated commitment to empirical evidence and its position on global warming may be summarized as follows. There is little doubt the carbon dioxide concentration of the atmosphere has risen significantly over the past 100 to 150 years from humanity's use of fossil fuels and that the Earth has warmed slightly over the same period; but there is no compelling reason to believe that the rise in temperature was caused primarily by the rise in carbon dioxide. Moreover, real world data provide no compelling evidence to suggest that the ongoing rise in the carbon dioxide concentration of the atmosphere will lead to significant global warming or changes in Earth's climate.

In the 17-year period since its creation, the Center has published over 5500 timely and objective reviews of scientific research reports on both the biological and climatological effects of atmospheric CO_2 enrichment. Accompanying each review is the full peer-reviewed scientific journal reference from which the review was derived, so that patrons may independently obtain the original journal articles and verify the information for themselves.

CO2 SCIENCE