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Global Climate Change: A Recent Paleoclimatological Perspective [BLOG]

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Preface...

Currently, climate change is a popular and important issue within the scientific community, the media, and with the general public. With that in mind, I want to highlight some recent climate events and transitions from a paleoclimatological perspective and discuss some factors in climate change, both past and present, and possible circumstances leading to the next glaciation. While this blog touches on current anthropogenic (human-caused) warming, the primary focus is to explore recent climate changes and events leading up to our current warming over the last ~12,000 years, possible causes and factors, paleoclimatic findings, and to take a look at future reglaciation and a hypothetical reglaciation scenario.

Paleoclimatology...A Brief Overview

Paleoclimatology is the study of the past climates of the earth's history. Paleoclimatology gives climatologists and other climate researchers a solid grounding in how the earth's climate has changed and how different factors have influenced the earth's climate system. It is a fascinating field of study because it involves not only atmospheric sciences and climatology but also includes disciplines in physics, chemistry, ocean sciences, geology, and history including archaeology and anthropology.

I have always been intrigued by the diversity and intricacies involved in determining past climate changes. There are many environmental changes that have occurred in the past that allow the reconstruction of ancient climates without the standard tools we use today for measurement. These indirect methods are called proxy indicators or proxies and help to determine timelines, temperatures, precipitation, atmospheric composition, glacial advances and retreats and many other climate variables. Proxies include the analysis of tree rings (dendroclimatology), coral reefs, ice cores, lake and marine sediments, peat bogs, fossil pollen, mineral deposits, [geomorphic features](#) and many more. The data from multiple proxies can then be compiled to [recreate an ancient climate](#).

The temperature, sea level, and CO₂ data used in this blog are obtained from a variety of established, recognized, accepted and published paleoclimate proxy data that were evaluated and determined to be reasonable for inclusion. The CO₂ data is obtained primarily from various ice core and air data or combined ice core and plant stomata data, which is more variable, where it was determined to be reasonable and acceptable. Since temporal and spatial resolution decreases as we go back on the geological time scale, reconstructing a past climate with proxies is not an exact science, therefore, in many instances I have used ranges and/or departure values to account for that uncertainty.

Not all climate events are global nor do they occur to the same extent at various locations or at precisely the same time. Some areas lag or lead especially as related to the southern hemisphere, which has a

different set of climate dynamics. There are also many hypotheses concerning what caused most of the earth's climate events and what causes the climate in general to change although there are also many agreed upon conclusions.

Radiocarbon dating is only accurate back to roughly 50,000 years ago so other means of analysis are used to determine climates in the distant past. Although there are many other ways to determine age, one of the most important is [isotope geochemistry](#). [Oxygen isotopes](#) are a valuable proxy in determining the past climates of the earth. The analysis of oxygen isotopes of cores drilled from the seabed and glaciers is an essential way to help determine past climate changes. The analysis of marine oxygen isotopes chronologically divides the earth into warm and cold periods called [Marine Oxygen Isotope Stages \(MIS\)](#). MIS stages are numbered and divide the earth's past climates into warmer and cooler stages with warmer stages being odd numbers and cooler stages being even numbers. Stages may be broken into sub-stages to differentiate different changing climate within a specific MIS. Normally the sub-stages are identified by letters. We are currently in MIS 1, the Holocene Epoch.

Our Current Climate...We're In a Period of Glaciation

The earth has been in the [Quaternary](#) glaciation period, the last of the earth's five ice ages, for ~2.6 million years and as long as we have glaciers we will continue to be in an ice age. The previous global [interglacial](#) period ended ~110,000 YBP (years before present) so it was about time, historically speaking, for another interglacial like we are now experiencing. The [Pleistocene Epoch](#), also known as the "Ice Age", had been going on for the last 1.8 – 2.6 million years depending upon the inclusion of the Gelasian Stage/Age, also known as the early Pleistocene, and ended with the current interglacial, the [Holocene Epoch](#). Although the Pleistocene Epoch has ended we are still in the Quaternary Period of glaciation. Numerous glacial and interglacial events occurred during the Pleistocene. Occasionally, up to 30% of the earth's surface was glaciated during this time.

Carbon...A Basic Look at its Effects and Significance on the Earth's Climate

Ice cores have shown that during these interglacial cycles maximum natural (notice I said "natural") CO₂ cycle levels do not initiate warming but have mostly lagged warming although other studies show that the CO₂ lag is not conclusive. The lag period is normally of very short duration, typically just several hundred years to possibly a millennium at most. Normally in past climate changes, warming begins followed by the natural escalation of CO₂ levels. Subsequently, due to positive feedbacks, warming is enhanced. Likewise, as glaciation approaches, temperatures begin to slowly fall thus starting a series of events that leads to lower CO₂. This is a simplistic trend and by no means implies that CO₂ can't be the initial driver just that CO₂ is not the initial primary driver in past climate changes. In fact, most warming occurs, sometimes up to 90% or more, after CO₂ begins to increase also. Currently, considering the rising CO₂ levels, anthropogenic ("unnatural") CO₂ is hypothesized to be more of a direct contributing factor, but still very limited IMO, to climate change than in the past.

The carbon cycle is an ever changing and evolving process involving the oceans, atmosphere, all living things on the earth, even the earth itself, and the dynamic interactions and chemical changes that take

place. Because all living things contain carbon, the carbon-based molecule is considered a building block of life and the changes it undergoes are very important. Without CO₂ the earth's greenhouse effect would be severely altered and we would have a much colder climate. The effects of CO₂ on climate sensitivity and other feedbacks such as clouds, water vapor, and [Albedo](#) are not well understood and still draped with much uncertainty.

Recently, one [study](#) using recent satellite information reveals increasing long wave (infrared) radiation emissions indicating a negative feedback but also increased incoming solar short wave radiation absorption. More research is needed to determine the sensitivity of the earth's climate to CO₂ and how that affects the earth's radiative equilibrium, more commonly referred to as the earth's energy balance. Since the oceans hold considerably more CO₂ than the atmosphere, the absorption and emission of CO₂ by the earth's oceans and associated [cryospheric](#) changes are also key factors in understanding any changes in the climate.

Climate Transitions...Some Causes and Events

From our current knowledge, it is commonly thought that [Milankovitch cycles](#) and solar influences are the primary drivers of climate change followed by other forcings and feedbacks such as geography, changes in atmospheric circulation, changes in ocean currents and circulations, clouds, greenhouse gasses (water vapor, carbon dioxide, nitrous oxide, methane etc.), chemical and dynamical atmospheric changes, albedo, volcanoes, tectonic activity and more. During maximum glaciations global average temperatures can run 5-10 °C colder than the present and many places in the northern hemisphere experience expanded glaciated land masses known as ice sheets. Here is a nice view of [how glaciation has moved](#) (must install Adobe Flash Player to run) over the last 180,000 years in North America. If you don't trust Flash Player, you can view this [link](#) without installing Adobe Flash Player but the animation won't work.

During glacials, periods of colder climate and glacial advancement are called stadials, and periods of warmer climate and glacial retreat are called interstadials. According to NOAA, during the last glacial period of the Pleistocene (~110,000-12,000 YBP) there were at least 25 warming climate events (interstadials) known as the [Dansgaard-Oeschger events](#), also called Bond events, and the less frequent Heinrich cold events (stadials). The warming events, although cooler than today's temperatures, came on very quickly, possibly within a decade or two and raised temperatures 5 °C or higher and then gradually cooled. They occurred at predictable ~1500 year intervals and typically lasted for a decade or less and usually cooled slowly over a period of several hundred years to, in some instances, a thousand years. The shorter, less frequent Heinrich cold events occurred on average about every 7,000 years and generally lasted a few centuries before tapering off over a period of less than a thousand years. These changes are thought to be caused by the North Atlantic [thermohaline circulation](#) (THC) or to have a solar influence though they are still not well understood.

Bolling-Allerod...The Prologue to Warming

We are currently enjoying the Quaternary interglacial warming of the Holocene Epoch over the last ~11,600 years as the [Younger Dryas](#) stadial signaled the end of the Pleistocene Epoch. Just prior to the Younger Dryas stadial event, the [Bolling-Allerod](#) interstadial from ~14,700-12,900 YBP marked the end of Pleistocene glacier advancement and the beginning of rising sea levels, which were helped along by [meltwater pulse 1A \(MWP-1A\)](#). Meltwater pulses cause a rapid rise in sea levels due to an influx of cold fresh water from melting glaciers and ice sheets. Global sea levels rose ~20 meters while Britain and Greenland temperatures rose ~15 °C in less than 500 years. Other North American sites also experienced significant warming of 8-10 °C and even South America warmed similarly. CO₂ rose moderately from ~210-230 parts per million volume (ppmv), therefore, only a very small part of this extreme warming can be attributed to CO₂.

There was a brief cooling period in some parts of the world during Bolling-Allerod. In those areas a brief Older Dryas (stadial/cooling event) is recognized as the separation of the Bolling and Allerod interstadial events. Because temperatures and sea levels began rising in earnest with the advent of Bolling-Allerod some consider Bolling-Allerod the start of the Holocene with the ensuing Younger-Dryas a short term dramatic cooling event of the Holocene and not a stadial event of the last glacial period. Yet others consider warming from the Last Glacial Maximum, which I will discuss later, as part of the current interglacial.

Younger Dryas...The Big Freeze

Abrupt climate transitions have occurred many times over the earth's history. The thirteen hundred year Younger Dryas stadial (~12,900-11,600 YBP) prompted a quick reversal of the global warming that was occurring during the Bolling-Allerod interstadial. During Younger-Dryas most northern hemisphere locations experienced cooling to varying degrees with the coolest being Greenland where ice core samples show temperatures cooling of 10 °C or more with ~50% of the cooling occurring over just a century or two then gradual warming of ~2 °C over the next millennium, then abruptly ending with even more rapid warming of 10-12 °C over just several decades. Temperatures in Greenland at the end of Younger Dryas were 3-5 °C warmer than at the start of the event, however, they were still 4-5±2 °C cooler than the Bolling-Allerod climatic optimum. Over the northern hemisphere cooling averaged 3-4 ±2 °C depending upon location, however, average global cooling was probably nearer to 1-2 °C due to warming in the southern hemisphere.

By comparison, today's temperatures are somewhat warmer than they were at the end of Younger Dryas. CO₂ was gradually increasing from 230-260 ppmv during Younger Dryas, rising linearly as it got colder and continuing a linear rise as it rapidly warmed. The Younger Dryas was a complex global event but rapid cooling was mostly in the northern hemisphere. Much less research has been done in the southern hemisphere and there is some conflicting evidence but current data tells us that there was most likely cooling in some areas but most places exhibited little to no cooling and some places such as New Zealand may have had warming. The tropics fluctuated slightly but were mostly unchanged.

Antarctica actually experienced warming during Younger Dryas but had cooled significantly just prior in a period known as the [Antarctic Cold Reversal](#) (ACR) ~14,500-12,900 YBP, which incidentally coincides closely with the warmer Bolling-Allerod interstadial warming event and MWP-1A in the northern hemisphere. As noted earlier, this timing lag is a common pattern of climate events involving the southern hemisphere and is sometimes referred to as the Bipolar Seesaw. Some studies also imply that the Dansgaard-Oeschger and Heinrich events are associated with the Younger Dryas event. It is now widely accepted that the Younger Dryas event was caused by the North Atlantic thermohaline circulation discussed above or the more involved [Atlantic Meridional Overturning Circulation](#) (AMOC) but many other hypotheses also exist, including an [impact event](#), and some contradictions are also indicated with the ocean circulation hypothesis.

Post Glacial Cooling...The 8.2KA Cooling Event

As the Holocene warmed after Younger Dryas, a sudden cooling event interrupted the warming. About 8,600 YBP cooling began to occur and ~8,200 YBP a rapid cooling event dropped temperatures by 2-3 °C and 3-6 °C in Greenland in a matter of a decade or less. By 8,000 YBP the cooling had abated. This cooling is thought to have been caused by ocean dynamics, specifically, the meltwater-induced changes to the thermohaline circulation caused by drainage from glacier lakes of the North American Laurentide Ice Sheet. Sea levels rose 1-2 meters from the fresh water discharge. CO₂ changes were negligible when compared to natural variability. Some recent studies using plant stomata indicate there may have been an ~25 ppmv fall in CO₂ levels. Prior to the event CO₂ levels were ~260 ppmv and had been slowly rising. While not nearly as impressive as the pre-Holocene Younger Dryas stadial event, it is certainly the most abrupt climate reversal of the Holocene. Once again the North Atlantic regions were the most adversely affected. Anomalies exist in certain regions and the southern hemisphere but the changes were felt worldwide.

Last Glacial Maximum...The Peak of Cold and Dry Begins to Slowly Change

The abrupt warming at the end of the Younger Dryas ushered in a warmer period of glacial retreat called the Holocene Epoch that continues to the present day. Our current warming, however, started before both the Younger Dryas and Bolling Allerod events at the [last glacial maximum](#) (LGM) ~21,000 YBP. At the LGM, the average global temperature was 5-6 °C colder than the present, sea levels were ~120 meters lower and CO₂ was ~180 ppmv. The earth was cold, dry and harsh. Initially, there was slight warming but an extended Heinrich event, which coincides nicely with the Oldest Dryas stadial, began cooling the North Atlantic ~17,500 YBP and lasted until ~15,500 YBP when pre-Bolling warming began ultimately followed by the dramatic warming of Bolling-Allerod.

As the Holocene warmed the North American ice sheets had completely disappeared by ~6,000 YBP. The entire Holocene has experienced small transitions such as the more recent Little Ice Age (~1350-1850 AD) and the Medieval Warm Period (~950-1250 AD). Some have also tried to call human induced warming over the last ~150 years another Epoch, the [Anthropocene](#), but one thing is certain, despite the current anthropogenic disruption, colder days are ahead and history clearly tells us that.

Climate Sensitivity...The Solar Effect

Fluctuation in energy received from the sun is a major factor in [climate sensitivity](#) and in any transition to glaciation or warming. Milankovitch influences such as orbital forcing (eccentricity, precession, and obliquity) along with internal forcings and the resultant disruption and you begin to have seasonal, glacial, and ice sheet deviations. The Milankovitch theory and its role in causing glaciations is being questioned and [defended](#). Notwithstanding the amount and distribution of solar radiation as a significant factor in the transition to glaciation is widely accepted.

The entire electromagnetic spectrum interacts at atomic and molecular levels in the atmosphere including the middle and upper atmosphere (stratosphere, mesosphere, thermosphere, and associated regions of the ozonosphere and ionosphere). Improving knowledge and understanding of solar intensity variations and how they affect energy balance and the corresponding thermal structure, chemistry, and dynamics of the middle and upper atmosphere is paramount in determining any accurate future changes to the climate. The troposphere, the atmospheric region nearest the earth's surface, continuously integrates with these regions and helps to shape our climate.

There is some great work currently being done at various institutes, laboratories, and universities worldwide that will help us further understand the influence of the sun on the climate. As Robert McQueen, director of the [High Altitude Observatory](#) (HAO) division of the National Center for Atmospheric Research (NCAR) from 1979 to 1986 commented "The radiative input from the sun is the driving force for all atmospheric motions. Anything that alters that radiative input in any way is important for understanding climatic variations and other large-scale changes in the terrestrial atmospheric system". In 2009, Dr. David Hathaway, a solar physicist at the Marshall Space Flight Center and now with NASA, said "This is the quietest sun we've seen in almost a century." In 2013, Dr. Hathaway said "I would say it is the weakest in 200 years" when speaking about the sun's solar maximum. As of 2014, according to NASA, incoming [solar radiation and activity](#) is "not impressive" in the latest cycle (Solar Cycle 24).

The most recent decline in solar activity has fueled rumors that levels similar to the 17th century Maunder Minimum could be reached during the upcoming decades but that is purely speculative at this point. Some solar experts think the Gleissberg cycle, a little understood occurrence that happens about every century, may be the culprit. As a result scientists are now looking more closely at the sun than ever before as a reason for the deceleration of warming since 1998 but recent trends since 2013 indicate warming is increasing once again.

When Will Glaciation Return....The Factors and the History

Solar radiation and activity is on the decline and paleoclimatic history and the Milankovitch cycles indicate that we are heading for a much [cooler time](#) in the not too distant future, geologically speaking, even with the increased CO₂ and any anthropogenic forcing. Ice cores show that frigid climate changes and increased glaciation can occur rapidly and last hundreds of years even during interglacials such as we are currently experiencing. Additionally, we are now nearly 12,000 years (15,000 years according to those who start the Holocene with Bolling-Allerod) into the current Holocene interglacial and ~20,000

years into warming from the last glacial maximum. Depending on atmospheric factors, Milankovitch cycles, [solar activity and variability](#), ocean oscillations and circulations, climate feedbacks and external forcings including CO₂ and other greenhouse gasses, and many other factors, the next glacial period may be imminent, which is unlikely, or as far away as 40,000 years or more (let's hope for the latter!).

Depending on the strength of our current anthropogenic forced warming, the known historical paleoclimate data analog, the accuracy of hypothetical mathematical formulas forecasting the next glacial period, and estimated future insolation, I suspect that sometime within the next twenty millennia and possibly up to forty millennia, probably sooner rather than later, the move to a much colder climate will be initiated as a result of reduced solar activity and insolation, atmospheric and ocean circulation changes, a gradual reduction of CO₂ due to the eventual depletion and/or reduction in the use of fossil fuels, and the Milankovitch cycles (most of the usual culprits).

Until then I expect, primarily attributable to anthropogenic forcing, another Holocene climatic optimum (or Anthropocene optimum if you prefer) within the next millennium and then a relatively stable but generally warmer climate for a few millennia with at least one abrupt cooling event interrupting or ending the warmer climate. Subsequently, I then anticipate ten to twenty millennia or more of an unstable climate before the factors delineated above gradually initiate a new glacial period. If our current warming accelerates as predicted, with its associated consequences, it could paradoxically be another dynamic prompted by glacial melting, atmospheric circulation changes and a disrupted thermohaline circulation, that triggers an abrupt cooling event and/or eventually moves us in the direction of glaciation. Conversely, our current warming could help to ward off glaciation for many thousands of years. The ultimate outcome is likely tens of thousands of years away. Luckily, we have plenty of time to prepare.

Usually the change to a colder climate is quite slow, on the order of thousands to tens of thousands of years. Most glaciations proceed gradually but, on occasion, can begin suddenly. History tells us that we can expect several cooling events lasting hundreds to possibly thousands of years before a permanent transition to a complete glaciation occurs unless a cataclysmic event were to hasten the change.

Glaciation periods have lasted on average 90,000-100,000 years before a brief interglacial period intervenes. That's a long time for a colder, drier climate! Historically, peak glaciation happens 40,000-60,000 years after a transition is initiated. Longer glacial periods can have multiple peaks. Some research over the last 10-15 years has us plunging into a much [cooler climate](#) in a matter of decades.

Our current warming will most likely preclude that from happening. In addition to the preparation for warming scenarios there is no doubt that the government, especially the Pentagon, has also done a great deal of research and knows the effects of an impending sudden cooling climate scenario. Trust me on that one!

Climate Transition...A Hypothetical Return to an Ice Age

Now that we know glaciation will return, here is my purely hypothetical take on how the next glaciation could happen. Keep in mind that these events could be escalated to the minimum time period if we are forced into the next glaciation by any sudden unexpected climatic or climate response event. Normally a disruption of ocean currents and circulation accompanied by an atmospheric response could cause a more rapid transition and possibly a more abrupt climate change.

The following human events are based on what we know today and could change drastically if new energy sources are indentified, agriculture adaptations are initiated, and any other unforeseen changes are introduced to civilization as we know it. With that in mind, the following climate scenario is based on a transition in the relatively near future to help understand the progression and destruction of the climate events and the impacts of a severely colder climate within the social, economic, and political spectrum. The climatic events are authentic and more realistic based on my knowledge and application of past climate events.

“As solar insolation diminishes and solar activity wanes, prompted by the melting of Arctic sea ice, atmospheric weather pattern changes, melting glaciers, and disrupted ocean circulations due to the next major meltwater pulse, snow begins falling in the lower elevations and latitudes of the northern hemisphere. Think “lake effect” type snows. Atmospheric circulation, ocean currents and the thermohaline circulation are disrupted, and the [Albedo effect](#) begins to cool the climate only this time many factors are converging to make it a long-term event. Winter snows in the northern hemisphere begin to last into late winter and spring, and the snow lingers throughout the summer in lieu of melting.

As the transition to the colder climate progresses, more severe weather and weather related events occur. As the years pass, summers become much shorter and longer winters continue to add to the ever increasing snowpack. Sea levels start to fall due to [eustatic](#) change, quickly at first and then a more gradual steady fall. As the cold sets in over a period of decades and centuries, whole ecosystems are disrupted and progressively destroyed. More rivers and lakes begin to freeze over and farmlands exposed to the cold and snow turn into desolate wastelands. The continued shortening of the growing season in mid latitudes yields less crops. With the abundance of plant life from the interglacial consuming CO₂, the depletion of fossil fuels, and the natural dissolving and formation of carbonates in the oceans, CO₂ levels slowly drop (~50% at the maximum glaciation) thus removing a vital element for plant life. Some animal species unable to adapt become extinct, plants not hardy enough to withstand the cold vanish, and the earth, especially the northern hemisphere, turns into an unpleasant place to live. Eventually, considering the ever increasing global population, food shortages arise and food prices escalate, and health problems become more prevalent. With fossil fuels depleted, energy prices skyrocket, unemployment soars, inflation runs rampant and economies start to crumble into recession and depression. Heavily populated areas that depend on agriculture are hit the hardest. Mass migration to escape the cold becomes noticeable. Widespread famine and malnutrition starts to cause physical changes in human development. Numerous wars break out as food and energy are in dangerously short supply.

As the centuries pass and the cold becomes more unbearable, glaciers of increasing size and mass will begin to descend from the mountains ever so slowly enveloping everything in their path replacing once warm and fertile farmlands and cities with layers upon layers of ice. The earth will become arid because most of the available water has condensed, fallen as snow, and is now locked up in glaciers.

As the centuries turn into millennia, sea levels continue to fall (probably over 100 meters by the maximum glaciation) and eventually coastal cities and especially northern port cities, if they still exist, become landlocked if they haven't already been overrun by glaciers. Ultimately the glaciers will collide and huge land masses will become giant ice sheets up to four kilometers thick.

Finally, the earth's crust will buckle under the massive weight of the glacial ice causing an [isostatic](#) lowering of sea levels. The earth's topography will be forever changed as river paths will be redirected, mountain terrain will be altered, new and expanding deserts will appear, and changing lakebeds will reshape the landscape. Thousands of miles will be scattered with glacial debris, [moraines](#), deposited along the way. Hold on for the long haul because it'll be another 90,000 years or more until another interglacial arrives to warm us back up from the deep freeze.

There may be some brief warm spells (interstadials) along the way but generally the earth, especially in the northern hemisphere, will become a dull, cold, arid planet and a very uncomfortable, almost intolerable, place to live. Only the mostly tropical and subtropical southern hemisphere will be conducive to life as we know it. If you move there now your descendants will thank you."

Well, there you go. Alarmist...undeniably: Dramatic...perhaps: Entertaining and thought provoking...hopefully: Realistic...possibly.

Glacials and Interglacials...History and the Last Transition

Studies show and most agree that the [Holocene climatic optimum](#) occurred about 5,000-7,000 YBP. Temperatures were near to slightly warmer than today, mainly due to warmer summers in the northern hemisphere, and CO₂ levels were ~260 ppmv. Sea levels were near or slightly above current sea levels. Some regard the climatic optimum as the start of a new colder cycle, however, I anticipate that we will reach and possibly exceed the previous optimum within the next millennium.

The four previous interglacials have been warmer than the Holocene by 2-5 °C although those [peaks were mostly sudden and brief](#). Sea levels have also been higher by as much as 20 meters during those interglacials. The mean duration of interglacials over the last million years has been ~10,000 years.

The [last interglacial](#), known as the Sangamon in North America (Eemian or Riss-Würm as it's known in Europe and Alpine areas), lasted 15,000-20,000 years. South America (Valdivia) experienced a similar climate change. The Eemian/Riss-Würm /Sangamon started ~130,000 years ago. The Eemian (MIS 5e) is being studied extensively because of its similarity to the current Holocene Epoch. Evidence indicates that there was a cooling period ~122,000 YBP in the mid-Eemian and that temperatures never recovered to the Eemian optimum. During the early Eemian global temperatures averaged 5±2 °C warmer than our current temperatures. After the mid-Eemian cool down they remained similar to today's temperatures.

Sea levels during the early Eemian stage were roughly 4-6 meters higher than today's but began dropping after the Eemian optimum. The Eemian interglacial began to cool (MIS 5d) by ~116,000 YBP and ended with a significant rapid cooling event ~110,000 YBP. This cooling signaled the beginning of a return to global glaciation including The Devensian (Britain), Weichselian (Europe), Würm (Alps), several in the South American Andes and later the Wisconsin (North American).

Meanwhile, the Sangamon interglacial started slightly after the Eemian and paralleled the Eemian. The Sangamon in North America wasn't quite as warm as the European Eemian and records from the Southern Hemisphere are similar with regards to temperatures during that time. Slightly warmer weather (MIS 5c) returned around 106,000 YBP but an unstable and cooler climate than the present by ~5 °C persisted as the Wisconsin glaciation in North America gradually began to expand and reach the northern parts of the US by ~80,000-75,000 YBP.

Some extend the Sangamon interglacial to ~75,000 YBP when the Wisconsin glaciation reached the northern parts of the US. North America was somewhat slower to glacialize than the European and Alpine glaciations thus the differing views of exactly when the Sangamon ended and Wisconsin glaciation began. Many overlap the time period for the start of the Wisconsin glaciation with the latter part of the Sangamon. CO₂ levels were in the 220-280 ppmv range during the Eemian stage and at the beginning of the last glacial period (~110,000-75,000 YBP). CO₂ levels during most of the last glacial period from ~110,000-12,000 YBP were 180-220 ppmv.

The Late Holocene...A Global Anthropogenic Carbon Problem

The current Holocene interglacial has been mildly warm and relatively stable compared to past interglacials, which have had numerous periods of frigid weather and increased glaciation along with warmer temperatures and retreating glaciers. Higher Holocene CO₂ levels, currently ~400 ppmv, are exceeding that of recent interglacials and have been attributed to humans. Since 2008, anthropogenic CO₂ emissions have stabilized and are trending downward in the U.S. and are also falling in many European countries but the boom in fossil fuel usage since the turn of the century in developing countries such as India and China, which is now nearly double that of the U.S., are driving worldwide emissions upward.

Undoubtedly, there has been anthropogenic involvement but the amount and contribution to warming is still in question as scientists try to understand the rate of decline in surface warming (1998-2013) which, according to some, may have been a [complete pause](#). Some think the trapped heat is going into the oceans, natural variations are at play, solar influences are changing, or even that the data may be incorrect and needs adjusted, which is a fairly common occurrence with scientific data.

The Future...Only One Thing Is Not in Doubt

With the pleasantly warm Holocene interglacial lasting longer than most recent interglacials our good fortune may be coming to an end if we look at the most recent history of the Quaternary Period. Paleoclimatic history and hypothetical mathematical models indicate that the next glaciation could occur within the next 30,000 years and any anthropogenic influence attributable to fossil fuels will be

slowly mitigated and eventually stabilized with most CO₂ ultimately being absorbed by the oceans or incorporated into sediment by the remains of marine life. An adverse affect of the oceans absorbing excess CO₂ is the release of hydrogen ions causing ocean acidification, which needs to be carefully considered as it may be harmful to some marine ecosystems. Although the absorption of CO₂ into the oceans will undoubtedly be a long process and fully take thousands of years to completely resolve that is a very small period in relation to the earth's geological time scale but is certainly worthy of mention and continued analysis.

Meanwhile, human ingenuity, adaptation, and innovation will find ways to reduce fossil fuel usage until they are exhausted, identify new sources of energy, and remediate any harmful effects. For now, we have higher CO₂ and a milder climate. The warming may actually be beneficial, at least in the near term, to perhaps delay or moderate the next cooling event or [inevitable glaciation](#). There is even a possibility of an abrupt cooling event caused by the fresh cold water from glacial melting as a result of current warming, which could disrupt the oceans currents and thermohaline circulation enough to take us into a temporary “Little Ice Age” or “Younger Dryas” type of cooling scenario or maybe even initiate a slow, gradual return to glaciation. That is unlikely but remains a possibility considering our knowledge and understanding of global climate change is still in its infancy, despite the huge advances being made.

A greater knowledge of the past greatly helps us to understand the future. Notwithstanding the current warming of the Holocene, the cold and dry weather of past glaciations will return, that is a given! It may take thousands or even tens of thousands of years but reglaciation will return and it will wreak havoc with life, especially in the Northern Hemisphere. We will once again have glaciers and ice sheets up to several kilometers thick along with long harsh winters and short cool summers at its maximum. Cold, not heat, poses the biggest threat and causes the most damage to human civilization and the earth in general. Although an extended warm climate can be damaging, a cold climate is devastating.

With the advent of Bolling-Allerod, warming over the last ~15,000 years has turned our climate from frigid to pleasant. Humans and plants evolved in the tropics and thrive in a warm climate much better than a glacial one so enjoy the warmth before the next glacial cycle starts and be glad you're living during an interglacial such as we are enjoying now!

Mike is a retired meteorologist, a former NOAA-National Weather Service employee, and a former employee of the DOD's U.S. Army Atmospheric Sciences Laboratory where he was an associate RDT&E meteorologist at White Sands Missile Range, NM, Poker Flat Research Range, AK, and eventually the Chief Operational and Research Meteorologist at Yuma Proving Ground, AZ. As a NOAA employee, Mike was a certified NOAA-NWS Weather Radar Operator, Weather Observer, Weather Forecaster, and Climate Data Analyst. Mike was also a certified DOD weather forecaster specializing in operational, environmental, and ballistic weather forecasting, military meteorology, planetary boundary layer, aeronomy (middle and upper atmospheric research), and meteorological research and project support (RDT&E).

View ‘About’ menu page at <https://www.climate.metman1.com> to see more. To read more about meteorology and Mike’s work experience and research related activities... Visit [Mike's Meteorology Page](#)

References: The links below are cited for their explanatory and informational contributions to this blog.

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Global Climate Change: A Recent Paleoclimatological Perspective

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