The end of the Holocene

Gary Wescom –October, 2020

Climate change has been studied and discussed for hundreds of years. Reconciling day-to-day weather and longer term climate trends with our scientific theories has been marginally successful. Unfortunately, the level of our knowledge reaches its limit when attempting to predict when we might expect the most damaging phase of climate change: The end of the Holocene!

An Ice Age

What is the Holocene? For the last 3 million years, the Earth has been in an ice age. Yes, that is correct. 3 million years. That may seem wrong to those who have not looked into the subject before this. This particular ice age has an interesting history. It is an on again, off again kind of thing. The Earth cools and ice advances for about 100,000 years and then abruptly warms for 10 or 20 thousand years or so. We are currently enjoying one of those interglacial warm spells. The one we are in geologists named the Holocene.

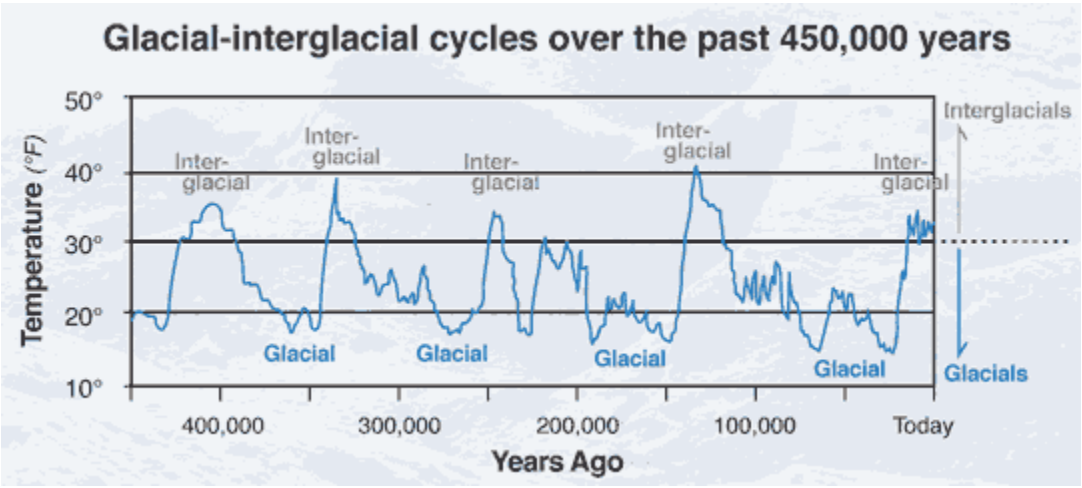

Figure 1: Greenland ice core 450,000 year temperature profile
(Graphic from Utah Geological Survey article listed below)

The figure 1 above shows temperatures on central Greenland over the last 450,000 years. The glacial – Interglacial cycle shows up well. The pattern is one of rapid, 10,000 years or less, temperature rise, followed by a 10,000 to 20,000 year warm period, which is then followed by an approximate 80,000 year gradual cooling. Of course, there are many smaller peaks and dips in temperature along the time line.

For a discussion on this subject see this Utah Geological Survey article:

https://geology.utah.gov/map-pub/survey-notes/glad-you-asked/ice-ages-what-are-they-and-what-causes-them/

I won't dwell on climatic conditions during the 80,000 year glacial advance. Mile deep ice over Canada and the northern states of the USA along with sea levels 400 feet lower than today should provide sufficient clue as to the hardships possible during that phase of our ice age. The current interglacial phase is what we should be considering.

Interglacials

You will notice that the most recent glaciations phase reached its maximum about 20,000 years ago. That was when the Earth began warming and mile thick ice in the northern hemisphere began melting. That was the beginning of the Holocene interglacial.

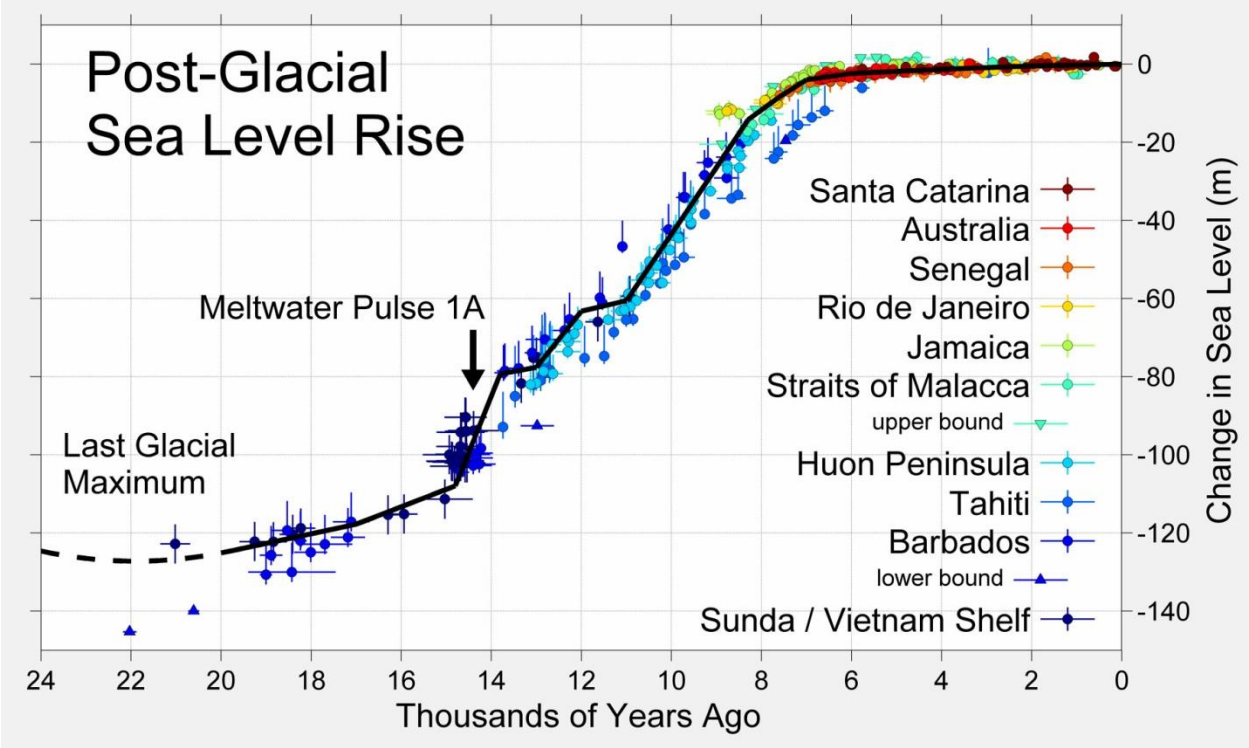

Figure 2: Wikipedia graph of Holocene sea level

Mile thick ice contains a lot of water. That water came from the Earth's seas, lowering their levels by over 400 feet. As the ice melted, that water flowed back into the seas. Figure 2 above shows the rise in sea level over time as glacial ice melted. The reverse will happen as the Holocene ends.

To understand what to expect might be ahead for the remainder of the Holocene, we could examine previous ice age Interglacials. Notice that interglacials begin with rapid warming followed by a slow cooling until reaching a glaciations phase. The glaciations phase increases the earth's albedo, reflecting more sunlight, increasing the rate of cooling. Notice also in figure 1 that the Holocene interglacial did not have a high initial temperature spike. It has a lower, flatter temperature profile than previous interglacials.

While it is difficult to know for sure, but it is likely the Holocene's flatter temperature profile may have been and still be a boon for human civilizations. Environmental and Climatology conditions have varied relatively slowly throughout the Holocene, at least compared to what might be expected with temperature profiles as seen during previous interglacials. As an example, the previous interglacial, named by geologists the Eemian, peaked nearly 10 degrees Fahrenheit warmer than the Holocene. After its temperature peak, Eemian dropped steadily into full glaciation. Each century in the Eemian would have experience continuous significant unidirectional climate shifts.

Interglacials and Civilization

The Holocene's comparatively slower temperature changes compared with previous interglacials have allowed civilizations to organize and grow before favorable environmental conditions failed them. The rich verdant marsh and lake area of the Sahara provided a millennium of reliable human habitable conditions. As the Sahara lakes and rivers eventually dried, its population provided a cultural and technological base for subsequent Nile civilizations.

Of course, the simplified view of Holocene climate is only generally accurate. Global temperatures rose to roughly current levels and higher thousands of years before sea level rise slowed. In recent decades, coastal cities established 9,000 to 10,000 years ago have been found, but in sea water depths of up to 100 feet. At that time, sea level was rising about one foot every 30 or 40 years.

The Holocene, though having a smoother climate profile than previous interglacials, has not been entirely benign. There have been many short term shifts. Productive agricultural times have alternated with droughts and floods. Civilizations have risen and fallen from the effects of those shifts.

It is unlikely that the rapidly changing climactic conditions of the Eemian or previous interglacials would have allowed stable large civilizations. The smaller and slower Holocene shifts in temperature have devastated civilizations. As the Holocene comes to an end, again the Earth will experience a comparatively faster drop in global temperatures. This should raise concern as to what dangers lay ahead in the coming glaciation phase.

Our Main Concerns

The questions we would like to have the answers to are:

- When will the Earth start to cool again?
- How cold will the Earth get?
- How fast will the Earth cool?
- How will we recognize the end of the Holocene?
- What do we do now?

Let's look at those questions separately.

When Will the Earth Start To Cool Again?

This is actually a trick question. As can be seen in figure 3 below, the Holocene temperature maximum was 8000 years ago. Earth's temperature has been dropping slowly since then. Over that time span,

there have been some up and down swings in temperature including the Minoan, Roman, and Medieval warm periods. Another significant period is what is called the Little Ice Age that ended about 150 years ago. Overall, the trend remains downward.

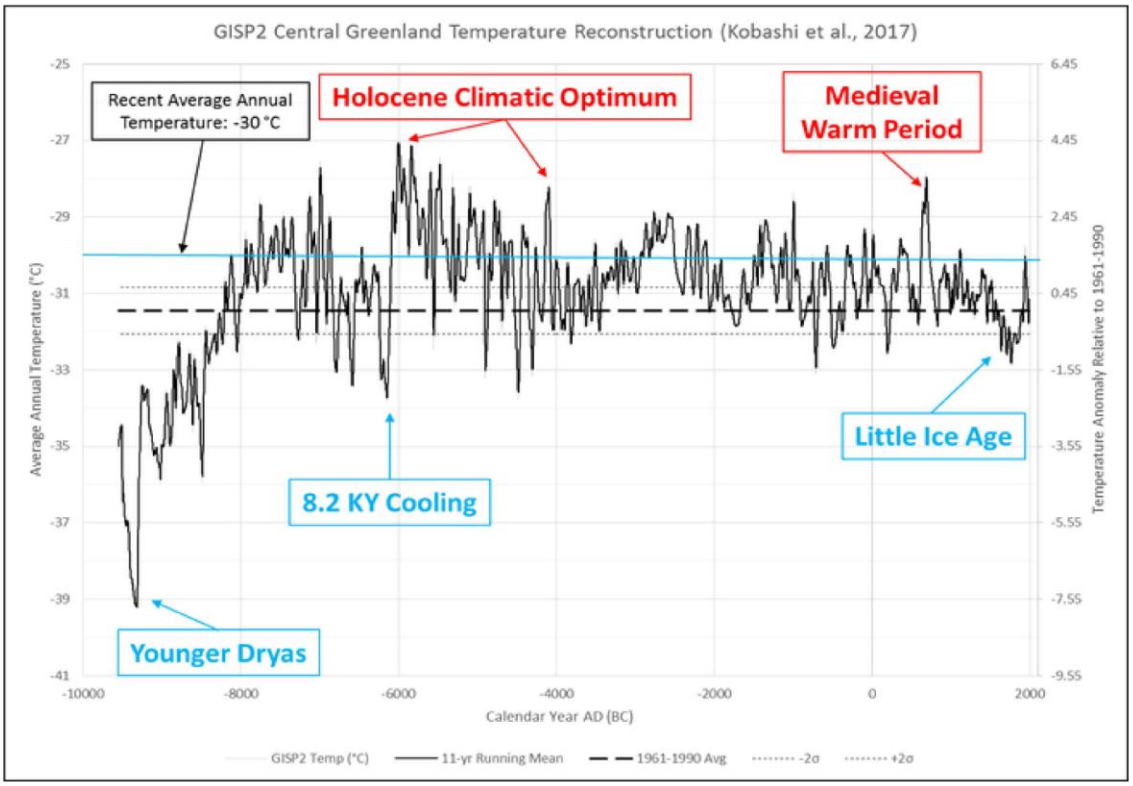

Figure 3: Greenland ice core Holocene temperature profile

It might not be obvious why Greenland ice core information might be important to this discussion. Glaciation advance begins at the north and south poles. As it glaciers advance, the Earth's albedo increases, reflecting more sunlight thus producing increased polar cooling. Greenland is a handy monitoring point as it has retained its glacial ice throughout the Holocene.

The depth of that ice has allowed us to collect ice cores providing a rough estimate of Greenland temperatures through several previous glacial/inter-glacial cycles. Based upon figure 1 above, Holocene temperatures have hovered only slightly above those when previous inter-glacial were dropping into full glaciation phases.

Of course, what we are really asking is: when will the downward temperature trend become a problem for human civilization? This is an awkward question to answer. Examining human history and technological advances over the last few centuries shows us that each new generation is incrementally more able to deal with possible climate temperature shifts.

The Holocene has already lasted about the average length of previous interglacial phases. The answer to the question of how soon will glaciation become a problem is: no sooner than Tuesday next week. We actually do not know well enough to improve on that number by very much. It could be next Wednesday or up to 2000 years from now. And even then, will we find it a problem?

How Cold Will the Earth Get?

Through isotope studies of ice cores from Greenland and other long term ice sites we have a reasonable idea what temperatures were during previous glaciations phases of the current ice age. That turned out to be about 10 degrees Fahrenheit cooler averaged globally with some areas 40 degrees cooler.

For comparison with those glaciations phase temperatures, let's look at what was called the Little Ice Age. North American and European temperatures reached about 3 ½ degrees Fahrenheit lower than at present. The Little Ice Age spanned from about 1300 to 1850 AD. As always with global temperature, there were some ups and downs with two significantly colder periods from about 1300 to 1500 and about 1650 to a bit after 1700. Full recovery of temperatures to near current temperature did not occur until around 1900 AD.

The coldest periods of the Little Ice Age were rough on humanity with plagues and famine common. When temperatures fall to Little Ice Age values and continue plummeting, human disaster is likely without extensive adaptation. Remember that glaciations phase temperatures cause ice to cover northern land masses a mile deep. Farming will have to move onto land uncovered by receding sea levels. There is little humanity can do but pack up and move toward the equator where there will still be ice free areas.

Here is some info on the Little Ice Age: https://www.eh-resources.org/little-ice-age/

How Fast Will the Earth Cool?

The most troubling question about cooling at the end of the Holocene is how fast global temperatures can drop. Humans are very adaptable. A slow temperature decrease, of say up to 1 degree Fahrenheit per century would be easily handled. Infrastructure and social norms vary significantly over a span of only a century. Each human generation will know the world as it is in their time and will make incremental changes so adaptation will not feel overly burdening in cost or effort. Faster temperature decrease will present a much different problem.

The Holocene interglacial was preceded by one named the Eemian. That interglacial began about 130 thousand years ago and ended about 115 thousand years ago. I say "about" simply because it is difficult to be very precise with dates that far back in time. It can be seen in figure 1 above. The Eemian interglacial and the subsequent entry into a glaciation phase suggest how the Holocene may progresses and end.

Greenland ice core analysis indicates that temperature there can drop 10 degrees in only 50 to 70 years. While this is Greenland information, it does indicate that we cannot rely on a slow gradual drift into glaciations phase temperatures. Rapid down and up temperature shifts seem likely. The overall trend will be slowly downward but decade by decade shifts could prove problematic.

Faster drops into glaciations phase temperatures, as might be expected, will be dangerous. Existing farm land can show greatly reduced productivity very quickly from shorter growing seasons with colder profiles. Changes in weather patterns will likely be large and unpredictable. Social upheaval of one kind or another is likely.

How Will We Recognize the End of the Holocene?

Realistically we will likely not recognize the end of the Holocene when it comes. Year to year and century to century climate variations tend to obscure the slow 8000 year temperature decrease from the Holocene temperature maximum. It is only when the entire Holocene temperature profile is examined after the fact that the downward trend will be obvious.

After the 500 year Little Ice Age, 20th century and early 21st century have shifted warmer than the long term trend. Examining the Eemian and Holocene temperature profiles appears to indicate that temperatures will eventually swing back to the long term trend values and likely lower. The question then will be whether that next cooler period will be temporary as was the Little Ice Age, lasting only a few hundred years maximum, or is it the start of a glaciation phase.

There is one particular 'Canary in a Coal Mine' worth watching. That is Iceland. Its location at the top of the Atlantic Ocean between the Labrador Sea and the Norwegian Sea is unique. Due to its northern latitude, the oceanic circulation currents, and its varied terrain it has some critical global temperature indicators: Iceland's glaciers have an important historic profile.

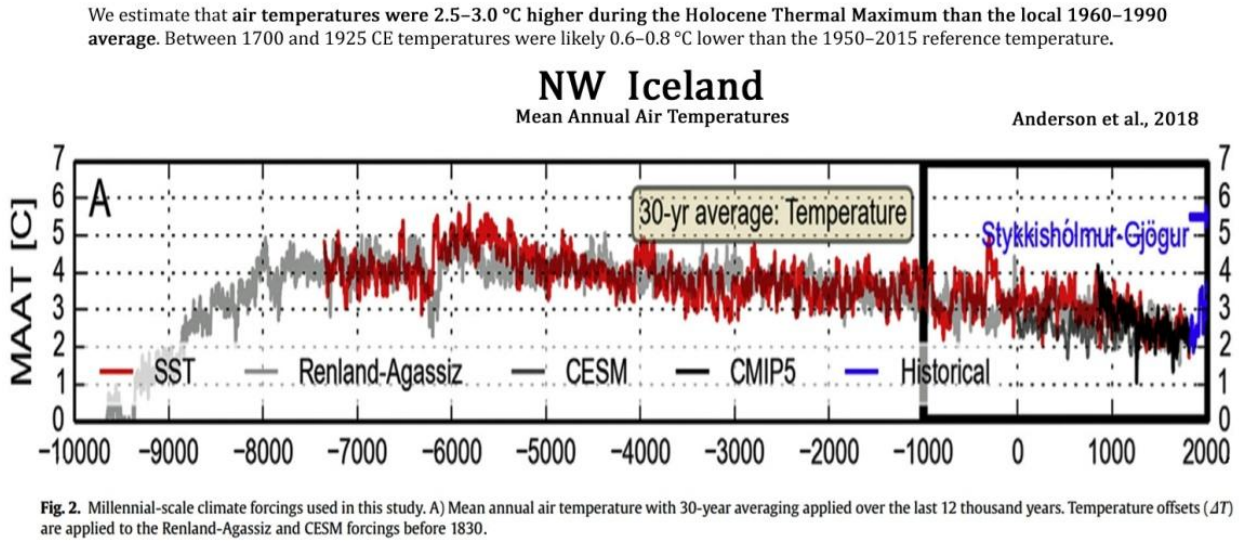

Fig. 2. Millennial-scale climate forcings used in this study. A) Mean annual air temperature with 30-year averaging applied over the last 12 thousand years. Temperature offsets (ΔT) are applied to the Renland-Agassiz and CESM forcings before 1830.

Figure 4: NW Iceland Holocene temperature profile

During the Holocene temperature maximum about 8000 years ago, Iceland was glacier free. While the island had many mountains high enough and cold enough for year round snow caps, it was not until 2500 years ago that the global temperature drifted low enough for glaciers to form and advance. Over the intervening centuries those glaciers advanced and retreated incrementally, gradually reaching their maximum lengths at the end of the Little Ice Age 150 years ago. Since then, though continuing to

retreat and advance, their lengths have generally shortened. This then is their value for signaling a likely end of the Holocene.

As long as Iceland's glaciers are retreating or at least not advancing, we can be confident that the Holocene is not ending. Those glaciers will remain available for monitoring for a very long time. It is unlikely that the Earth's average temperature will rise again to what it was 2500 years ago before those glaciers began to develop.

What Do We Do Now?

Planning for an end to the Holocene is tricky. After all, it might not happen for a couple thousand years. Any efforts we expend now could easily be wasted. Humanity's capability for handling problems will likely improve tremendously in future centuries. 500 years from now, our current level of knowledge and technological capability will seem quite primitive. Adapting to the next glaciations phase of this ice age we are in should be handled by those who experience it, using the techniques and technology of whatever century that is.

A Final Reminder

Earth's climate has varied over a large range over its existence. For millions of years prior to now, ice and cold has dominated. We are in one of the short respites from that cold. We should enjoy the balmy climate we enjoy today but never forget that it will come to an end.