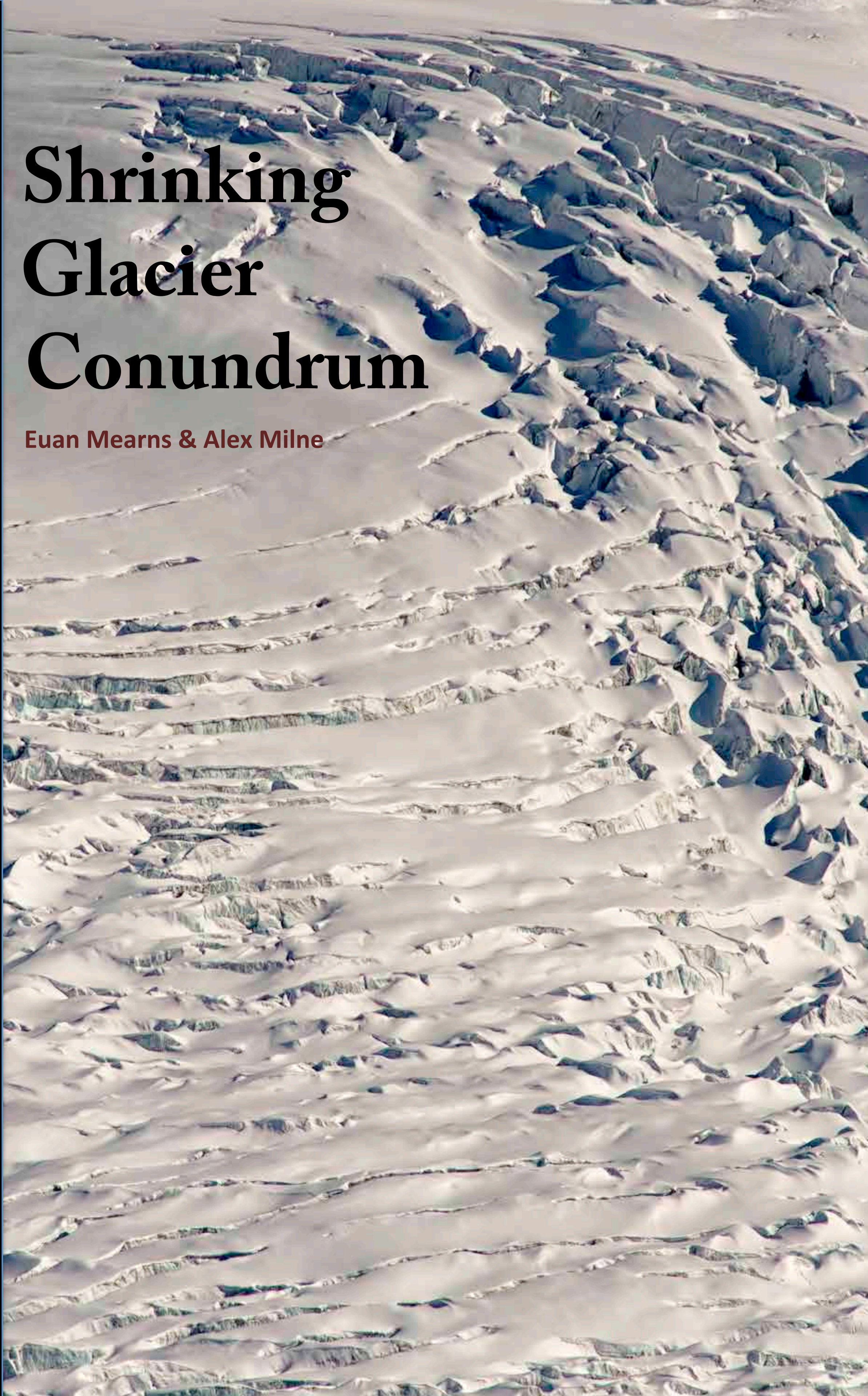
The Shrinking Glacier Conundrum

Euan Mearns & Alex Milne



Geology Glaciers and Climate Change

Preface

The Shrinking Glacier Conundrum (SGC) is a build on a paper initially published in the 2016 Alpine Club Journal which we are making available as this eBook.

The world's glaciers are clearly shrinking and average temperatures are rising. Climate is becoming more unpredictable and extreme and the media increasingly hysterical. Politicians have fed on the hysteria bandwagon and are chasing votes. The current meme is one of saving the planet from the excesses of human activity. We all want to save the planet. But how robust is the scientific reasoning behind these statements? The "SGC" makes the case for an alternative hypothesis, the "Earth Orbit and Magnetic Activity hypothesis". It argues that anthropogenic activity, although important in raising greenhouse gases, is not the governing factor, in the current global warming of our planet. The book outlines how Earth is in a constant state of climate change and how the observed cycles can be explained through geologic time.

The authors acknowledge the input and help of Roger Andrews in the content and Ed Douglas as editor of the Alpine Journal.

Euan Mearns January 2018.

Introduction

In the Spring of 2017, I photographed the alpine glaciers, during a six weeks peripatetic drive around a very warm and snow starved Alps. Everywhere I went the theme was consistent; the alps are getting warmer and the big snow storms of winters past are getting fewer.

As I climbed towards Chamonix in my car above Sallanches, I got that first classic glimpse of the Blanc and it was rather shocking. The Mont Blanc Du Tacul snow field, glinting in the evening light, was clearly stressed, with deep crevasse cracks, in a way that I had not witnessed before. These features had developed in the two years since I last visited the valley. Shrinking and collapsing glaciers was a recurring theme as I traveled from La Grave in the west to the Dolomites in the east. Climate change is real and worrying and you can see it when you visit todays alpine glaciers. Witness these images of the Tour, Bossons, and Gigli glaciers.

Local people are rightly concerned as they observe their local glaciers receding significantly during their lifetime. That the world is warming is beyond doubt. Nevertheless the key question remains one of intense debate; what is driving the temperature increase and is the anthropogenic influence the dominant one? The scientific world is polarised on this; sadly the media, and consequently politicians are not. Undoubtedly there are major consequences for us and future generations. Are we tackling a problem that does not exist or are we too late in tackling the problem? These are key questions that we have to answer. The Shrinking Glacier Conundrum paper, since publication in 2016, has received both positive and understandably negative reviews. Such is the controversial and emotive nature of this topic. A consistent theme however has been approval that the counter argument to anthropogenic global warming has been put.

Read on and enjoy and please join the debate on the Energy Matters website.

Alex Milne January 2018

The Shrinking Glacier Conundrum

By Euan Mearns and Alex Milne

Anyone who has visited the Alps regularly over the last 40 years, walking, skiing or climbing, will recognise that the glaciers are retreating. The popular narrative in the media and among energy policy makers is that melting glaciers is down to climate change, which is undoubtedly true. In this article we examine the evidence for the cause of this climate change. Is it down to Man and CO_2 emissions, which is now widely assumed to be the case, or can glacier retreat be down to natural causes? This article focuses on the latter point.

We are both geologists, and we appreciate more than most that we live on a restless planet that is in a continual state of flux. One of the first facts to appreciate is that Earth is actually in the middle of an Ice Age that began 2.8 million years ago. This fact is easily forgotten but is manifest by ice that covers large portions of the planet in Antarctica, Greenland, the Arctic Ocean and in mountainous areas like the Alps where ice caps and glaciers are common place. Since the Ice Age began there have been approximately 50 periods of glacial advance and retreat. The glaciations, where ice sheets covered much of Europe and N America are punctuated by inter-glacials that have more benign climate. That is where we are now, in an inter-glacial called the Holocene that began about 12,000 to 10,000 years ago.

The main characteristic of inter-glacials is that ice melts at those times. Ice sheets expand during ice ages and retreat during inter-glacials. The status quo of no change does not exist on the real Earth although this condition of climatic equilibrium appears to have become engrained in the minds of those who study and model Earth's climate. Ice sheets and glaciers, in a state of continual flux, must either grow or contract. We should consider ourselves extremely lucky that we currently experience retreat of ice since ice sheet advance and onset of a new glaciation would be totally disastrous for mankind.

That is our first message. There is absolutely nothing unusual about glaciers melting during inter-glacials. But in this article we want to try and provide some understanding of the geological processes that are responsible for the cyclical advance and retreat of ice sheets that began 2.8 million years ago. This takes us into the world of plate tectonics, Earth's orbital cycles around the Sun, cycles in solar activity and the geochemical data that record all this information in ice cores from Antarctica and Greenland and sediment cores drilled in the deep ocean basins.

The temperature story from the ocean basins

Foraminifera are microscopic creatures that forage in the water columns of the deep oceans. Their skeletons are made of calcium carbonate ($CaCO_3$) otherwise known as calcite. It is the same material that seashells on the seashore are made of. When they are alive and growing, foraminifera extract calcium, carbon and oxygen from seawater to make their shells. Oxygen has 2 isotopes of interest - ^{16}O and ^{18}O and the ratio of these isotopes in a shell depends largely but not only upon the water temperature at the time the foraminifera was alive and growing. When the foraminifera dies, it sinks to the ocean floor and is slowly covered in mud and buried to become a fossil. The oxygen isotopes (abbreviated to $\partial^{18}O$) lock in the temperature of the water that prevailed during its life. Measuring $\partial^{18}O$ in a series of foraminifera from boreholes can therefore provide insights to past temperature changes and climate.

The LR04 stack (Figure 1) is one of the classic geochemical data sets compiled in recent decades [1]. It comprises 38,229 individual $\partial^{18}O$ measurements made on foraminifera from 57 boreholes from around the world, but concentrated in the Atlantic Ocean basin. The data cover from 5.3 million years ago to the present day. In Figure 1, time passes from left to right with the present day to the right of the plot. The vertical axis plots $\partial^{18}O$ with the scale inverted so that warm is up and cold is down. There are a number of key observations to be made. The first is that throughout, the $\partial^{18}O$ (temperature) oscillates with a semi-regular rhythm. From 5.3 to 2.8 million years ago $\partial^{18}O$ was low and temperatures were high and the amplitude of oscillation was low compared with what followed.

After 2.8 million years the amplitude of oscillation increases with the lows progressing steadily towards colder temperatures. 2.8 million years ago marks the onset of the Ice Age and formation of ice sheets in the northern hemisphere.

Plate tectonics and the Gulf Stream

Why did Earth enter an Ice Age 2.8 million years ago? Two macro-scale plate tectonic events may offer a partial explanation. The first is the formation of the Panama Isthmus about 4.6 million years ago [2]. The isthmus was formed by on-going subduction of the Pacific Ocean Plate beneath the N and S American plates creating the mountain chain that runs from Alaska to Patagonia. Closure of Panama drastically altered the pattern of ocean circulation and in particular it created the conditions for the establishment of global thermohaline circulation that would have profound impact on the climate of areas like NW Europe. In the North Atlantic, this global current is known colloquially as the Gulf Stream because it moves warm water from the Gulf of Mexico northwards creating climate that is uncommonly warm and wet for the latitudes of the UK and Norway. The global thermohaline circulation goes under a number of names and for simplicities sake we will simply call it the Gulf Stream in this article.

As they move northwards evaporation makes the waters of the Gulf Stream increasingly salty and the water cools. These processes combine to increase the density of the water that eventually sinks in the N Atlantic off the coast of northern Norway. The freezing of the Arctic Ocean every winter also creates cold dense water that sinks. Combined, these processes that cause surface waters to sink, are the engine that drives thermohaline circulation.

In the last 5 million years Antarctica has also been drifting southwards covering the S pole about 1 million years ago. This created conditions for a large permanent ice sheet with a knock on effect to global atmospheric circulation and climate. The creation of this ice sheet cooled the Earth by increasing albedo (reflectivity). All the sunlight that lands on Antarctica now gets reflected straight back into space.

Combined, these processes are believed to have created the conditions for the growth of ice sheets on Greenland, Europe and N America. The LR04 stack indicates a failed attempt for the Ice Age to begin 3.3 million years ago (Figure 1). And we would have to wait another half million years before things would get going properly.

Orbital Milankovitch Cycles.

There is one final ingredient believed to be required to trigger the Ice Age and that is the configuration of Earth's orbit. Russian physicist Milutin Milankovitch was the first to recognise that the patterns of variation seen in ice cores could be explained by subtle changes in Earth's orbit and gives his name to these Milankovitch cycles. Three components were identified:

Precession 21,000 y
Obliquity 41,000 y
Eccentricity 100,000 to 400,000 y

These three components all act simultaneously and are illustrated in the inset of Figure 1. Eccentricity describes Earth's orbit around the sun that varies between near circular to slightly elliptical. During the elliptical phase the distance between Earth and Sun varies on its annual orbit.

Obliquity is a measure of the angle of tilt of Earth's axis that varies in a complex cyclical fashion between 22.5˚ and 24.5˚ (Figure 1 inset). It is obliquity that gives rise to seasons on Earth. When the N pole is tilted towards the Sun we experience N hemisphere summer and when it is tilted away from the Sun, as the Earth makes its annual journey around our star, we experience N hemisphere winter. When the obliquity angle increases Earth experiences greater and more extreme seasonality with longer summers and longer winters. The Arctic circle moves S with increasing tilt. Longer winters may result in more high latitude snow fall combined with longer summer melt and it is not clear which would win through to incept or end a glacial cycle.

Precession describes rotational wobble around the Earth's axis.

How these components have varied over the last 5 million years and will vary 1 million years into the future are shown in Figure 2.

To get straight to the point, Figure 1 appears to show that the 41,000 y obliquity cycle permeates the data both before and after the onset of glaciation 2.8 million years ago. Following the onset of glaciation, the amplitude of temperature oscillation increased. 1.2 million years ago the pattern changes to longer cycles and it is widely reported that the 100,000 year eccentricity cycle took control.

In fact, examination of Figure 1 shows that very few of the cycles have 100,000 y duration and our analysis points to multiples of 41,000 y being in control (Figure 3). In fact the glaciation begins with 82,000 and 80,000 y cycles – multiples of 41,000. It seems that the 41,000 y obliquity cycle rules the Ice Age climate but its not that simple. A close examination of obliquity with LR04 shows that obliquity is sometimes in phase and sometimes out of phase with the LR04 observations (Figures 4 and 5). This puts a real joker in the pack since it shows there are no hard physical rules that link the glacial state to obliquity. Sometimes the ice melts when the angle of tilt is high (Figure 4) and sometimes Earth is in the deepest part of a glacial cycle (Figure 5).

The last turning point of the obliquity cycle occurred 10,000 y ago (0.39548 radians tilt) that just happens to coincide with the termination of the last glaciation and onset of the Holocene. Obliquity is now rising (0.40909 radians today) and we are half way to the next turning point maxima. But there doesn't seem to be any rules, which leaves us wondering if the imperfect orbital alignments might be a red herring.

Dansgaard – Oeschger Events and Bond cycles.

Dansgaard – Oeschger events are rapid warming cycles recognised in ice cores from Greenland. In ice cores the d18O of the ice water also provides a proxy for temperature. In Figure 6 the temperature profile for the GISP2 ice core is compared with the equivalent part of the LR04 stack. Note that on this chart time passes from right to left.

The macro scale structure of the two records are in splendid agreement but in detail there are clearly many differences too. One has to bear in mind that the GISP2 ice core is recording the air temperature at the summit of the Greenland ice cap while LR04 is recording temperature change throughout the Worlds oceans. The very large thermal mass of the oceans means that they respond more slowly to change and do not record short-lived local events as recorded on the Greenland summit.

Before going on, we want to draw attention to one fundamental difference between the ice core and oceanic data during the Holocene, i.e. the last 10,000 years. In this period the oceans appear to have continued to warm slowly since the Ice Age ended. This alone may account for the recorded global warming and sea level rise that so much fuss has been made about. And since the slow warming trend began 10,000 years ago it clearly has nothing to do with Man burning fossil fuels. In contrast, the ice core data shows more constant temperature and if anything shows a recent cooling trend. Its is such uniform temperatures seen in ice cores from Greenland and Antarctica that has given rise to the notion of uniform, unchanging climate on Earth. Note that the temperature on the Greenland summit is -30˚C.

The most obvious difference between the two records is the presence of the high amplitude D-O temperature spikes in GISP2. Note that the warm spikes are still -40˚C compared with less than -50˚C during the cold intervals and -30˚C during the modern interglacial. The D-O events are quasi periodic, sometimes regular, sometimes 2 or 3 cycles merge into 1 and sometimes much smaller than the 10˚C norm. There are about 4 or 5 D-O events in 5000 years giving a duration of between 1000 and 1250 years per event. The origin of the D-O events is not understood with certainty but a leading contender to explain them is cyclical shifts in the intensity of the Gulf Stream [6]. This is interesting since we have seen that the creation of the Gulf Stream may be implicated in creating conditions for the Ice Age to begin, and now we see that oscillations in the Gulf Stream may influence the intensity of cold on Greenland. The D-O cycles are all but absent in ice cores from Antarctica suggesting they are local to the N Atlantic basin. They are not visible in the oceanic LR04 stack.

14,000 years ago there was what seems to be a larger than normal D-O event that threatened to bring the glaciation to an end. But the ice did not give up its grip at that time and the Younger Dryas cooling was the last gasp of the last glaciation.

Turning our attention to the Holocene it can be seen that the D-O events appear to have continued but on a much smaller scale. The forces that caused the Gulf Stream to oscillate appear to still be active but with much reduced effect when the Gulf Stream is in full flow as it is today.

What physical mechanism may lie behind the D-O events and hypothesised oscillations in the Gulf Stream? Once again isotopes from ice cores provide a clue. This time we look at the concentration of 10Be which is called a cosmogenic isotope because it forms in the atmosphere through the action of cosmic rays on oxygen and nitrogen. Berylium is a solid and therefore falls out of the atmosphere in rainwater and snow where it may accumulate in ice.

The main control over the concentration of 10Be in ice is the snow fall deposition rate. The higher the deposition rate the lower the concentration of 10Be. But the rate of production of 10Be is not constant. The combined magnetic field strength of the Sun and the Earth shields the Earth from galactic cosmic rays. Thus when the field strength is high the rate of 10Be production falls and vice versa.

Figure 7 shows the 10Be concentration through part of the GISP2 ice core where the concentrations have been corrected for the snow fall deposition rate. What we can see is that each D-O event is closely aligned with a 10Be anomaly but there are many more 10Be anomalies than there are D-O events. We count 20 10Be events from 15,000 to 38,000 years giving a mean 10Be event duration of 1150 years. The numbered D-O events 2 to 8 follow Alley [4] but it can be seen that many more small amplitude D-O events may be present when the temperature data are compared to 10Be. For example small D-O events may be present at 10Be events 2, 7, 10, 11 and 15.

These data suggest that cyclical changes in solar activity are linked to D-O events and by inference the Sun is implicated in creating rhythmical changes to the Gulf Stream. How could that be? This will be discussed later, but for now it suffices to say that changes in solar activity may impact the pattern of atmospheric circulation and winds. Changing wind patterns may affect the Gulf Stream and climate in general.

The final part of this story, that is zeroing in on the present day, comes from the mineralogy of sediment core samples from the N Atlantic. Bond et al [8] identified three geological markers : volcanic glass from Iceland; iron stained grains from E Greenland and Svalbard and carbonate grains from N Canada. The absolute and relative abundance of these grains in the sediments was observed to vary and Bond et al postulated that this was a reflection of the patterns of drift ice movement in the N Atlantic during the Holocene. Stacking all their data from 4 boreholes produced the North Atlantic drift ice index (Figure 8). The cyclical variation is quasi regular with 10 cycles in the last 12,000 years giving a 1200 year duration that is similar in length to the D-O cycles.

The Bond cycles may be viewed simply as alternations between warm and cold N Atlantic. Bond et al suggest that the northern part of the Gulf Stream was periodically truncated by the Labrador Current that cut across the N Atlantic bringing much colder conditions to Europe. The Bond cycles also correlate with 10Be suggesting that variations in solar and terrestrial magnetic activity was once again the driving force.

One interesting aspect of the Bond data is that it overlaps with written history. For example, Roman times are presumed to have had a more clement climate since among other things vines were grown in the N of England, Hannibal crossed evidently ice free Alps and the Roman era came to an end with deteriorating climate and Northern tribes encroaching onto Roman territory. The time of the Roman Empire has become known as the Roman Warm Period (RWP) and stands out as a prolonged spell of warm North Atlantic waters (Figures 8).

Less is known about the Dark Ages apart from they were dark and austere, neverthless in Medieval times civilisation once again flourished with Vikings trading around the globe, settling S Greenland and Newfoundland under a climatic regime that was probably more benign and pleasant than today (Figure 8).

The Medieval Warm Period (MWP) eventually gave way once again to deteriorating climate in the circum N Atlantic with the onset of The Little Ice Age (LIA) where long cold winters became common if not the norm. Viking history relates the encroachment of sea ice around S Greenland and Iceland making communication with Europe in their wooden long ships more hazardous. The Viking colonies on Greenland eventually died out. It was at this time, as documented by Jean Grove [9] that the last major advance of Alpine glaciers took place. It is from this cyclical advance 500 years ago that the Alpine glaciers began their cyclical retreat that continues to this day. The cold conditions of the

Little Ice Age that gave way to the Modern Warm Period are written into the sediments of the N Atlantic (Figure 8).

Physical process

We have seen how Earth's climate is restless, continuously changing and how in the North Atlantic realm, changes in the strength and configuration of the Gulf Stream may have caused the Ice Age to begin 2.8 million years ago and how fluctuations in the Gulf Stream as documented in Atlantic sediments and ice cores cause quasi-periodic fluctuations in climate on a time-scale of circa 1000 to 1250 years. We are in the middle of the most recent warming episode which explains in part why Alpine glaciers are retreating. We have also seen how the Bond and D-O cycles correlate with cosmogenic 10Be without fully understanding why this should be the case.

Danish physicist, Henrik Svensmark has proposed that increased bombardment by cosmic rays at times when the Sun sleeps may increase the nucleating rate of clouds. The creation of cloudier conditions may explain cooling and the onset of mini cold spells [10]. But clinching evidence to support this theory has yet to be found.

The winter of 2010/11 brought extreme cold weather and plenty snow to western Europe. This happened at a time when the Sun had grown anomalously quiet when compared with the 80 years that had gone before. Scientists and the public could observe the conditions that may have prevailed during the Little Ice Age. The jet stream had become more meandering with large loops sucking Arctic air off Siberia and blowing it over Europe. Lakes and rivers that hadn't frozen for many decades froze that winter. So much for global warming.

Researchers at the UK Met Office perhaps provide the answer [11]. Satellite measurements of solar output during the last solar minimum in 2010 found a higher than expected decline in mid-ultra violet radiation (UV). UV radiation is trapped by ozone in the upper atmosphere and less UV would result in cooling at high levels. The Met Office team was able to model this effect and showed that it could result in the modifications observed in the jet stream resulting in extreme cold winters.

Man will only be able to fully understand the causes of natural fluctuations in Earth's climate once we have the opportunity to observe these fluctuations in action using satellites. Changes in the spectral emissions from the Sun that correlate with the Suns level of geomagnetic activity is a leading contender. Following a period of hyper-activity from 1933 to 2010 the Sun has now become very quiet and will likely remain so for another 30 years. We may be about to find out if this marks the return of cold and snowy winters to Europe.

Glacier Retreat in the Modern Warm Period

How therefore can we observe these phenomena in our modern glaciers? Glaciers are controlled by a combination of addition, mainly through snow fall in winter, and ablation at the snout, mainly in the summer [see for example 8]. Modern research into the recent behaviour of the Mer De Glace glacier (MDG) confirms that the glacier is currently retreating on average at 9 m per year [12]. Nevertheless in years of substantial snow fall there is evidence that the glacier has advanced. The MDG it is estimated has retreated by 1.27 kms since records began in 1878 AD. The implication from the historical data is that the MDG has been retreating since the Little Ice Age. The key issue is whether this retreat has accelerated due to the influence of the dramatic increase in CO_2 since the beginning of the industrial age. Currently there is no compelling evidence in the MDG research for an acceleration in the retreat. Further more rigorous research is required to unravel the influence of CO_2 emissions, which will be challenging given the on going natural glacier retreat.

There are a number of interesting historical corollaries to the scientific evidence. In an alpine context it is speculated that during the time of Hannibal when he crossed the Alps in 218 BC, in the Roman Warm period, that in fact there were no glaciers and this enabled him to cross the high passes with his elephants. There being no glaciers on the illustrations of that time!!! Furthermore, wood (sub-fossil trees) from beneath the MDG give dates that range from 666 to 3671 years demonstrating that the tree line was much higher in the past giving clear testimony to past climate that was warmer than today. [12]

In conclusion the current glacial retreat observed around the world is the product of a long ranging climatic warming that commenced five hundred years ago at the end of The Little Ice Age and onset of the Modern Warm Period. Our belief is that this is part of an on going glacial cycle that can be tied to the Sun's activity. The effect of the recent CO_2 spike in the Earths atmosphere may in part be contributing to the recent global temperature increases, but it is unlikely, given the long ranging evidence of glacial cyclicity, to be the controlling factor.

Finally given the choice, would we rather have global warming or the alternative, global colding, and the extension of the glacial systems into our alpine valleys, with the devastating outcome that this would have on our alpine villages?

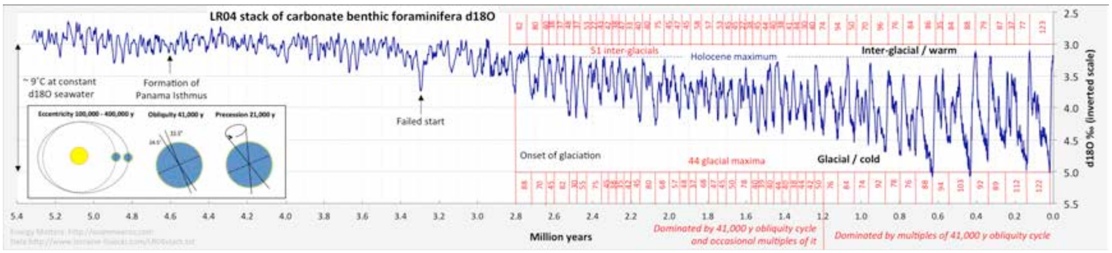


Figure 1 The LR04 stack [1] of d18O isotope ratios for benthic foraminifera from the ocean basins provides a record of global temperature change. The data are plotted so that warm temperatures are up and cold temperatures are down and time is passing from left to right. 2.8 million years ago there is an abrupt change where cyclical fluctuations in temperature begin to trend towards much lower temperatures. This marks the onset of the Ice Age. The Ice Age is characterised by glaciations (cold phase) interrupted by inter-glacials (warm phase). Earth is currently in an inter-glacial called the Holocene that began 10,000 to 12,000 years ago. The inset illustrates the three orbital cycles that are believed to influence glaciation. In red, the cycle lengths are marked from which it can be seen that glacial cycles appear to be dominated by the 41,000 y obliquity cycle and multiples of it (Figure 3).

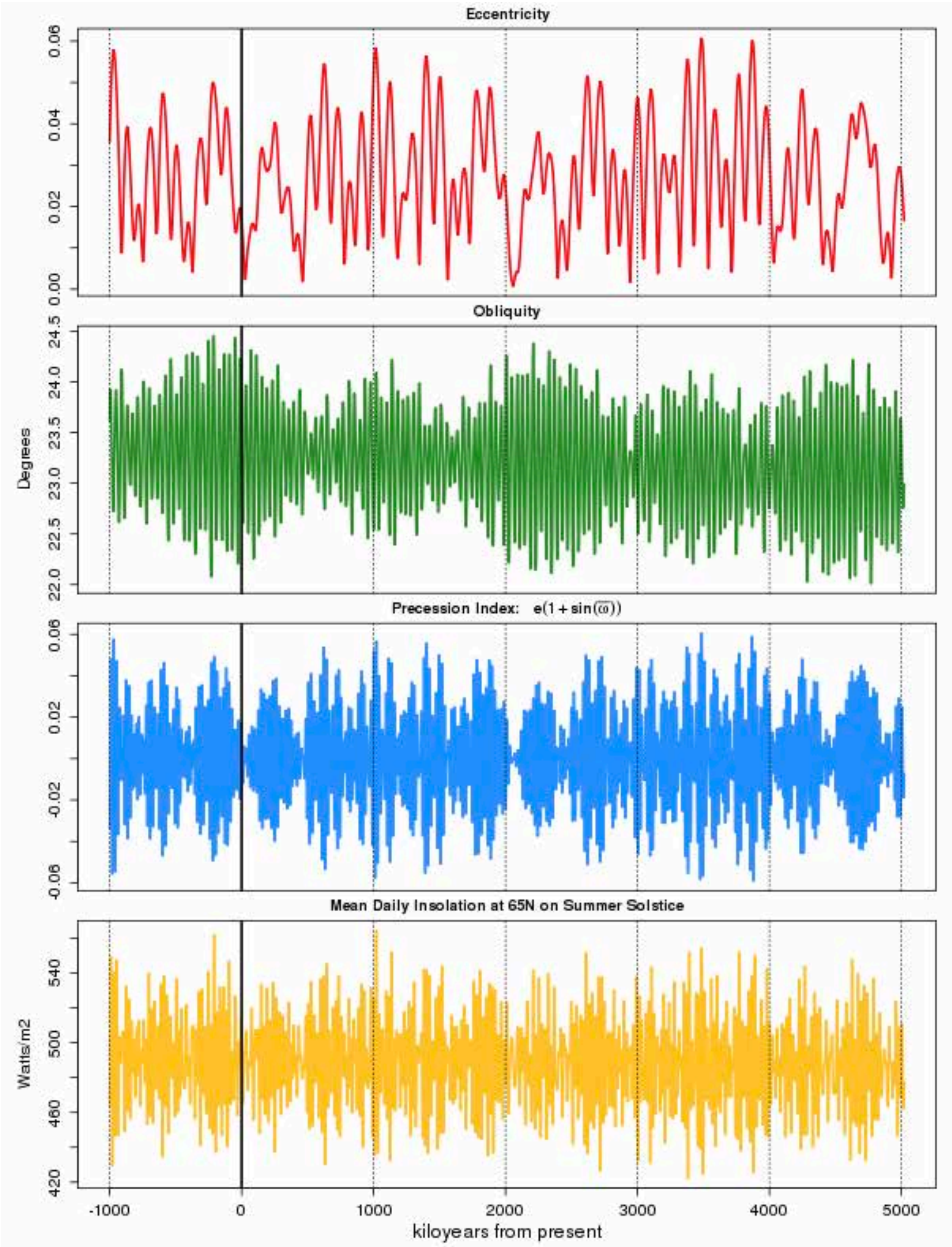


Figure 2 The charts show how the three orbital cycles have behaved during the last 5 million years and are also projected 1 million years into the future [3]. The total amount of solar energy (insolation) arriving at Earth does not vary much with these cycles, but the distribution of where it arrives does as illustrated in the lower panel. The variations in insolation arriving at 65°N are quite substantial and 2.7 million years ago values less than 430 W/m2 were

encountered for a short spell. Whether this was enough to trigger the onset of N hemisphere glaciation is an interesting question.

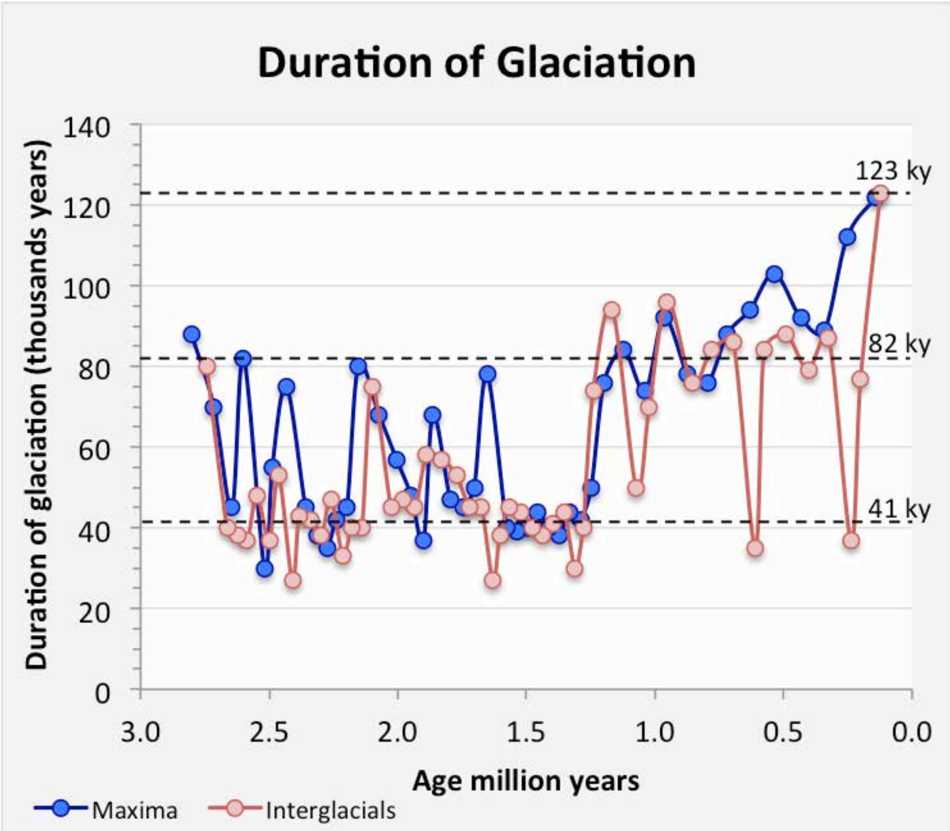


Figure 3 This chart displays the glacial cycle lengths as read from Figure 1. Note that the time between cycle peaks and troughs is not always the same. It has long been claimed that the 100,000 year eccentricity cycle expressed itself 1.2 million years ago. There is little evidence for that in these data that appear to vary according to multiples of the 41,000 year obliquity cycle. Lisiecki and Raymo [1] do say that the ages of samples from different boreholes are aligned by tuning to the 41,000 year signal. It may be possible that this statistical adjustment has given rise to this cycle length dominating the profile.

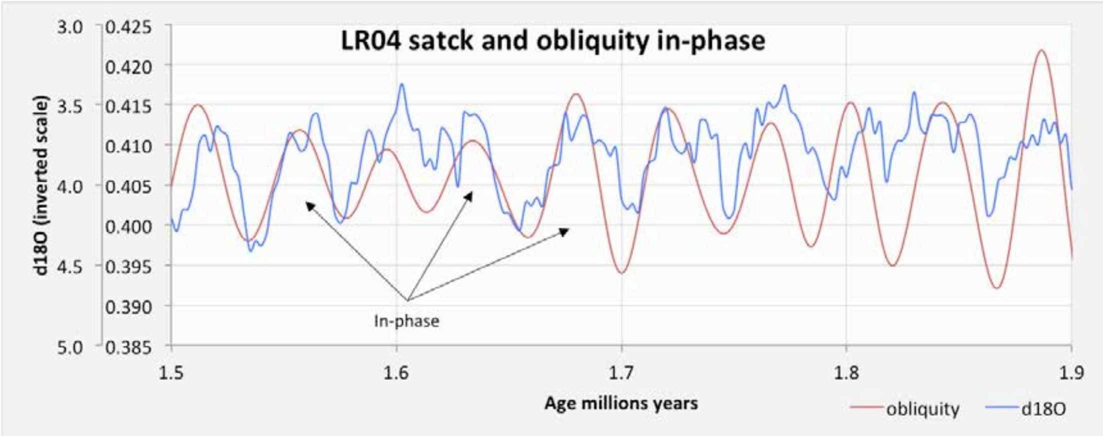


Figure 4 A more detailed look at the co-variation of orbital obliquity and temperature shows that from 1.5 to 1.9 million years ago obliquity and temperature were in-phase, temperature rising with high obliquity. LR04 $\partial^{18}O$ from [1] and obliquity data from [3].

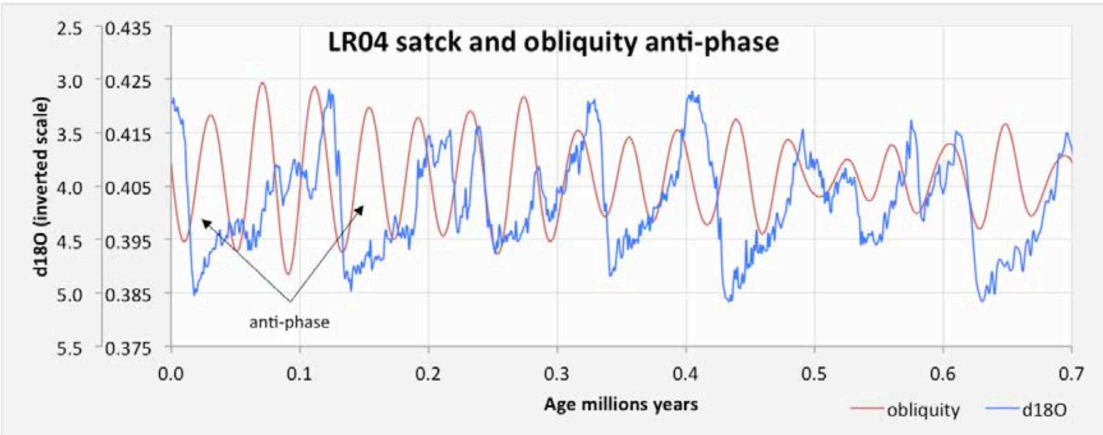


Figure 5 Looking at the interval 0 to 700,000 years we see that the in-phase relationship described in Figure 4 does not hold and there is a greater tendency for intense cold during the high obliquity part of the cycle.

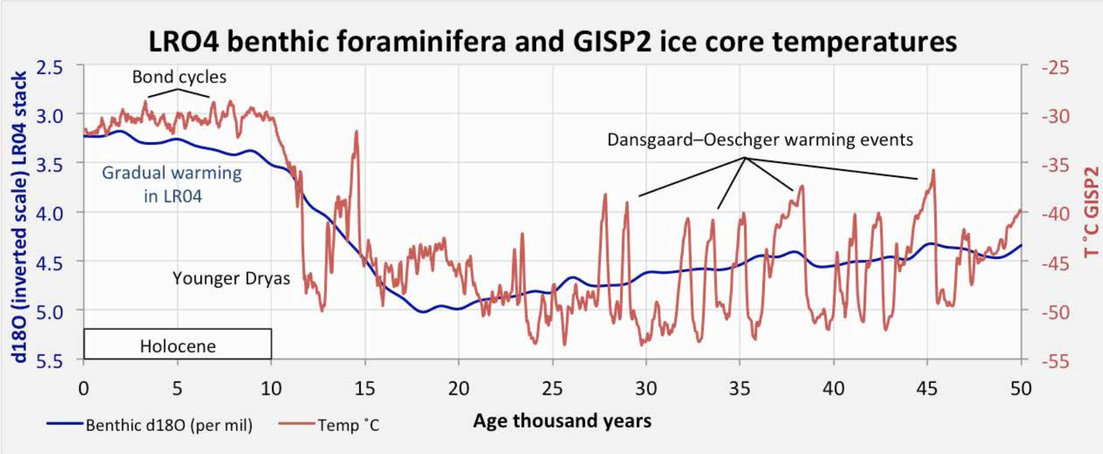


Figure 6 This chart compares temperature from the GISP2 ice core from Greenland (Greenland Ice Sheet Project) with the LR04 stack. The macro-scale agreement is excellent but the details are quite different. The GISP2 temperature data are from [4] downloaded from [5].

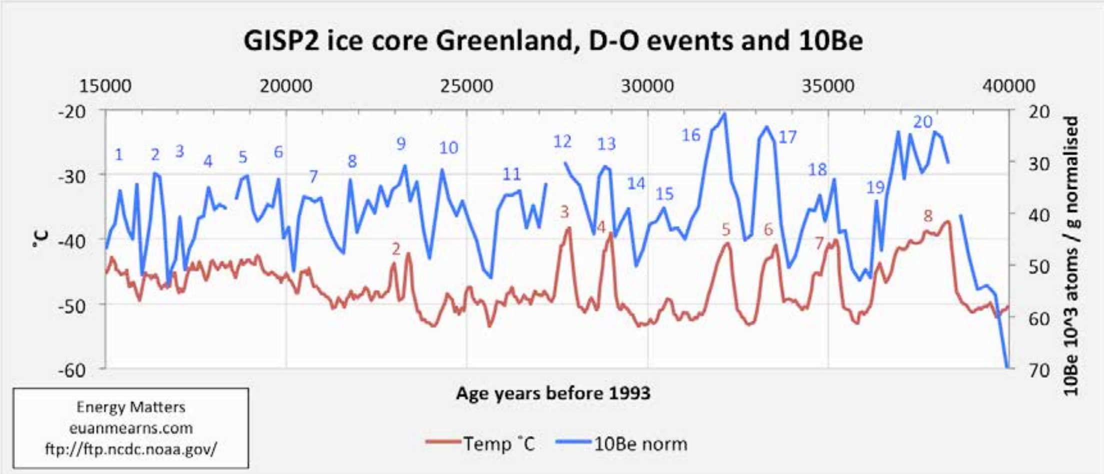


Figure 7 Comparison of temperature and 10Be in the GISP2 ice core [7]. The 10Be concentrations are corrected for ice deposition rate [5] and should therefore reflect the rate of 10Be production in the atmosphere via the action of cosmic rays on oxygen and nitrogen. Note that the 10Be scale is inverted. The main variable controlling cosmic ray penetration on Earth is the Sun's magnetic field that is carried by the solar wind. When The Sun is active, i.e. covered in Sunspots, the magnetic field is strong shielding Earth from Cosmic rays and 10Be production falls. It can be seen quite clearly that the warm D-O events labelled 2 to 8 [4] correspond to periods of active Sun.

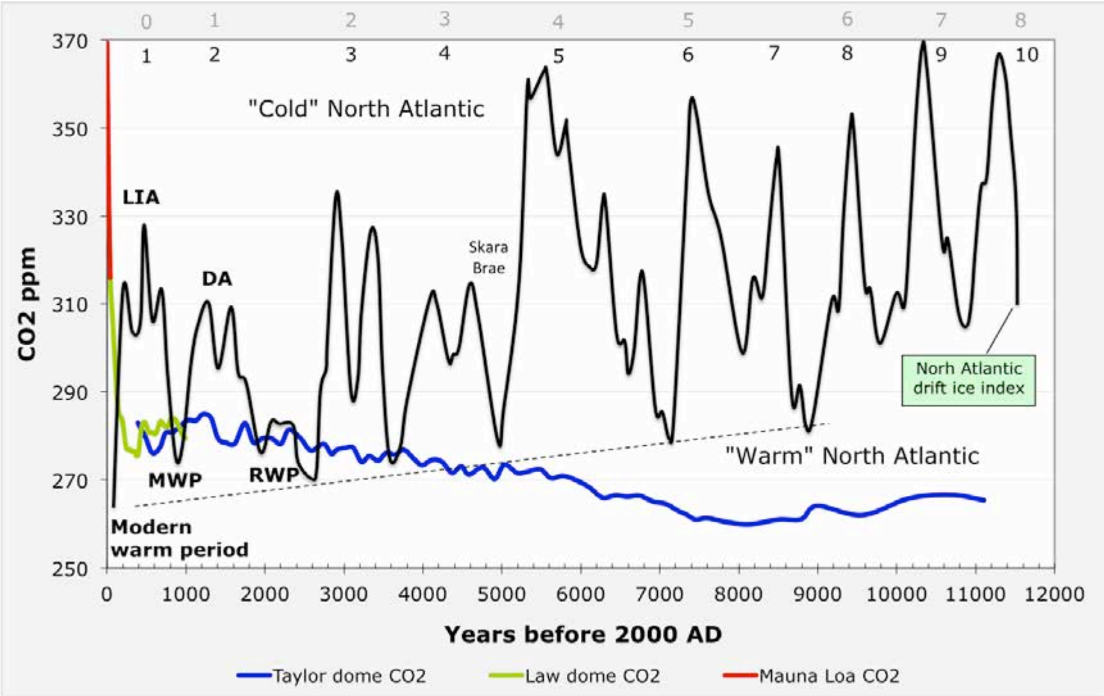


Figure 8 The black trace labelled "North Atlantic Drift Ice Index" is copied from Bond et al [8] and is a measure of drift ice activity in the N Atlantic. When the index is high this means icebergs drifted much further south than today implying cyclically cold N Atlantic waters. The drift ice index shows no correlation with CO2 apart from during the current "Modern Warm Period" where the rise in temperature and CO_2 can be viewed as coincidental. The Bond cycles also correlate with ^{10}Be and with historic evidence for cyclical climate change in the N Atlantic realm: RWP = Roman Warm Period; DA = Dark Ages cold period; MWP = Medieval Warm Period; LIA = Little Ice Age. At the very top in grey are the cycles 0 to 8 as labelled by Bond et al . I have re-labelled these 1 to 10 in black.

Dedication

This book is dedicated to the late Professor Nigel Trewin whose rigour, guidance and significant efforts helped us as under-graduate students on the road to our scientific careers.

Images

The images were taken by Alex in the Spring of 2017. The images document the effects of global warming on these glaciers. Not only are the glaciers shrinking, clearly they are collapsing near their termination and in places forming melt holes within the glaciers. Evidence, if it were needed, that our climate is changing.

The receding snout of the Bossons Glacier.

Dramatically developing crevasses on the Glacier Des Bossons

Le Tour Glacier with Aiguille Du Tour. A recurring theme, the glacier is collapsing and breaking up.

Snow starved crevasses March 2017 in the Argentiere Basin.

Aiguille De Bionnassay. Large scared face where seracs have fallen and scarred the north face.

Geant Seracs, Mer Du Glace. Getting bigger and opening up a second section above the three skiers.

Mer De Glace below Geant Seracs. Active moraine erosion


Skiers descending on the classic Vallee Blanche on the tremination of the retreating Mer De Glace Glacier. with seasonally thin snow cover.

Melt holes within the Gorner Glacier connecting to channels and small intra glacial lakes / ponds.

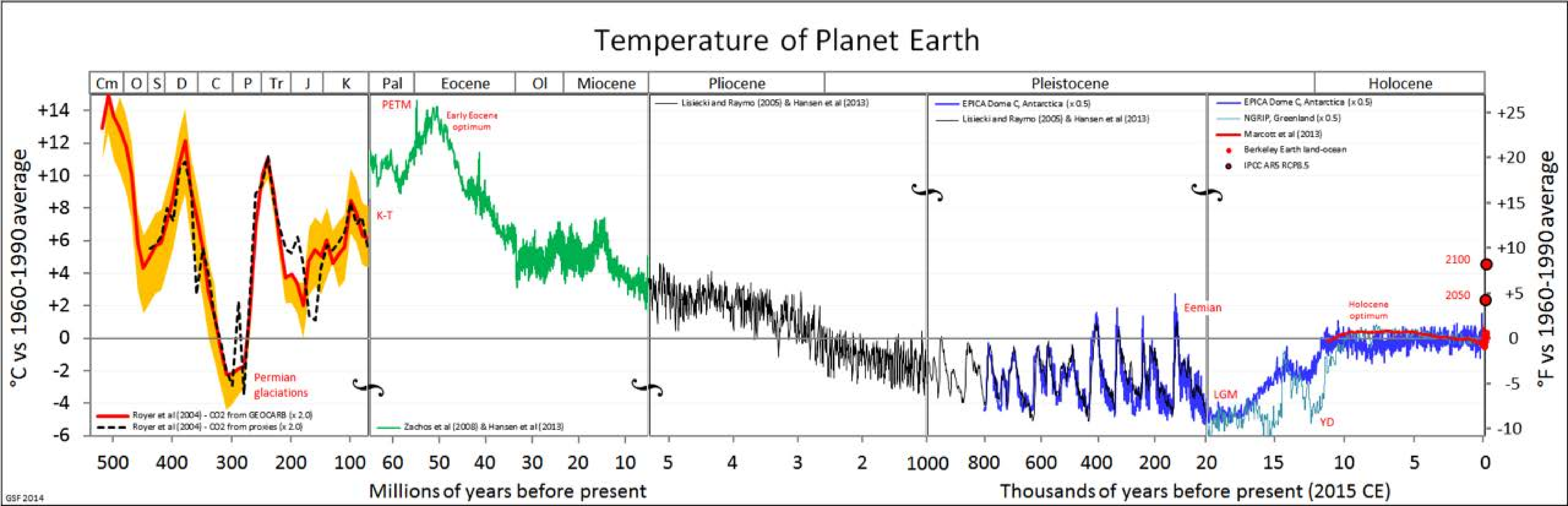
Turning a glacial corner; intersection of two trends. Border Glacier, tributary to the Gorner Glacier.


The collapsing and retreating Gigli Glacier on the Jungfrauhoch

View from the Marmolada summit in a snow poor March 2017

The connection between the Marmolada and Arabba regions of the Dolomites. Showing a lack of snow and the importance of piste management to keep the snow slopes open in seasonally warm weather. This area uses significant amounts of precious water resources generating artificial snow each year.

The road to Arabba. A major Dolomites ski centre. Mainly reliant on artificial snow during the snow poor 2017 ski season. The roads criss-cross and dive under the ski slopes.



Temperature of Planet Earth
Cm
O
S
D
C
P
Tr
J
K
Pal
Eocene
Ol
Miocene
Pliocene
Pleistocene
Holocene
°C vs 1960-1990 average
°F vs 1960-1990 average
PETM
Early Eocene optimum
K-T
Permian glaciations
Royer et al (2004) - CO2 from GEOCARB (x 2.0)
Royer et al (2004) - CO2 from proxies (x 2.0)
Zachos et al (2008) & Hansen et al (2013)
Lisiecki and Raymo (2005) & Hansen et al (2013)
EPICA Dome C, Antarctica (x 0.5)
NGRIP, Greenland (x 0.5)
Marcott et al (2013)
Berkeley Earth land-ocean
IPCC AR5 RCP8.5
Eemian
LGM
YD
Holocene optimum
2100
2050
Millions of years before present
Thousands of years before present (2015 CE)
GSF 2014

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From Euan's blog posts on Energy Matters

The Vostok Ice Core: Temperature, CO_2 and CH_4

The Half Life of CO_2 in Earth's Atmosphere Part 1

Catastrophic Climate Change – a reminder of what the IPCC actually said.

Global Warming and the Irrelevance of Science

The Residence time of CO_2 in the atmosphere is ……………33 Years

What if the world cannot cut it's Carbon Emissions

Carbon emissions, carbon intensity and the global trade in CO_2

Bio

Euan Mearns has BSc and PhD degrees in geology from the University of Aberdeen. He is an avid hillwalker and nordic skier. He has been blogging on Energy and Climate change issues for ten years. He passionately believes that the fossil fuel plus CO_2 is bad and renewable energy is good meme is over simplified and threatens to undermine the fabric of modern society and science.

Alex Milne is a petroleum geologist based in Aviemore. He has climbed, skied and trekked extensively in the Alps, Africa, the Karakoram, the Himalaya and his native Scotland. He specializes in mountain photography and is never happier than to be out in the mountains exploring photographic opportunities.

Contact

euanmearns.com

alexmilnephotography.com