

Revealing the Global Warming Signal

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1. The statistical meaninglessness of the global average temperature

Analysis of datasets of Earth surface temperatures from instrumental records and reconstructions from proxies should take into account vital metadata, measured knowledge about cyclic influences, annotations of overall climatic regimes and unique short-term events, that can enable informed analysis. "The climate system...has multiple components with physically distinct characteristics...basic physical considerations argue strongly against the notion that the global average surface temperature has a single characteristic time scale, or time constant." (Foster et al., 2008). Discussion of uncontextualised curves can be counter-productive (BBC, 2010), as the appliance of inferential statistics and other numerical techniques has been contested as inappropriate (Kelly and Jones, 1996; Mann et al. 1998; Rahmstorf, 2006; von Storch et al., 2004, Wahl et al. 2006), given that variables forcing the thermal response of the climate cannot be assumed to behave in a Gaussian probabilistic fashion, be unmodulating over time, be independent of each other or be guaranteed to have linear effects. Much is now known about internal cyclic variability, and unrepeatability influences such as random volcanicity, the time parabola of industrial aerosol ejection, major fire seasons and the profiles of short-lived "climate shift" re-organisations (Miller et al., 1994), so it can be claimed that the climate system is no longer a black box, and should not be mathematically treated as such. A reasonable axiomatic assertion can be made that the rapid accumulation of greenhouse gases in the atmosphere is causing a regular time-varying response, but that this can only be revealed by systematically deducting the impact of other well-studied signals. As the climate system is composed of ongoing and random events, and suffers episodes of localised non-linearity, with suggestions of chaotic bifurcation thresholds and hints of multiple stable states, this is not facile. The development of a standardised "resolved" global temperature

dataset with less noise would be a useful communication tool. Published and tracked over time, it could give a clear visual signal of whether the thermal response is departing from the projected pathway - a useful policy tool. The detection and attribution of global warming using datasets of real world observations that are filtered for known effects is a valuable exercise that corroborates modelling of the radiative forcing on the climate system. One representative study of this kind has resolved the underlying global warming trend as continuously and consistently rising. "Global-mean surface temperature is affected by both natural variability and anthropogenic forcing...identifying and removing from global-mean temperatures the signatures of natural climate variability over the period January 1900 [to] March 2009...filtered from the record, the residual time series reveals a nearly monotonic global warming pattern since [about] 1950." (Thompson et al., 2009).

As part of a fully comprehensive method, in order to be confident that millennial-, age- or even epoch-scale changes are not influencing current temperature evolution, it is first necessary to consider our place in geological time by summarising the outcomes of paleoclimatological research. Then, it is necessary to consider all the lines of evidence that parametrise modern era climatic influences, developing indices (indexes) of their magnitude and duration, enabling their effects to be deducted from the total at all points, to reveal the underlying global warming signal. It is also necessary to isolate and remove errors in instrumentation, which may result from changes in instrument choice or method, or bias owing to the distribution of measurements, or other features of data collection. Only when the residual anomalies are revealed is it appropriate to discuss statistical analysis of the radiative forcing of global temperatures.

2. Our place in geological time

2.1 The 6 billion year time scale

This time period includes the accretion of the Earth. The carbon dioxide concentration in the Earth's early atmosphere was very high, and this was only significantly reduced and replaced with atmospheric oxygen when life forms emerged that respired oxygen, and minerals became oxygen-saturated, starting some time after 2.5 billion years ago (Anbar et al., 2007; Bolin et al., 1979). Evidence suggesting the sequestration of carbon dioxide by the "biological pump" and weathering can be seen in the "descending stairway" glacial periods of the Vostok ice core record of the last 800,000 years (Jouzel et al., 2007). Aside from periodic interglacials, major volcanism and extinction events (Ward, 2006), the tendency has been towards less carbon dioxide in the atmosphere, and less greenhouse effect on global temperatures.

Current trend of surface temperatures on this timescale : **gradual cooling.**

2.2 The 500 million year timescale (Phanerozoic)

The GEOCARB III project and other research into deep time proxies from the emergence of multicellular life, show that over the last 500 million years the Earth has cycled between an "ice house" and a "greenhouse", and that we are currently experiencing the low point of a Great Ice Age, with significant glaciation of the polar regions (Royer et al., 2004). Evidence from the previous cold state, the "Permo-Carboniferous", which had a similar continental layout on the Earth's surface as today, and could be analogous, shows continued glaciation for around 50 million years. The current Quaternary "ice house" has been running for less than 50 million years and so could be expected to continue.

Current trend of surface temperatures on this timescale : **overall cooling since around 250 million years ago (Royer et al., 2004, Figure 4), and currently stable in the low temperature range.**

2.3 The 65 million year timescale

The permanent glaciation of Antarctica occurred around 34 million years ago (DeConto and Pollard, 2003, Figure 2c). Commencement of episodic glaciation of the Northern Hemisphere is thought to have been possible since around 25 million years ago (DeConto et al., 2008), and extensive glaciation of the North Pole region occurred around 3 million years ago (Lunt et al., 2008). There is evidence of several major spikes and optima in temperature including the Palaeocene–Eocene Thermal Maximum (PETM) at 55 million years ago (Bloom, 2010; Zachos et al. 2008 Figure 2). These have been attributed to various external forcings such as large volcanic or mantle plume emissions of carbon dioxide and methane from the Earth's interior, or changes in the deep ocean currents or sea level, causing the sudden release of methane from subsea hydrate provinces (Davy et al., 2010; Bice and Marotzke, 2002). Overall, however, the general trend has been a reduction in temperatures.

Current trend of surface temperatures on this timescale : **generally falling.**

2.4 The 5 million year timescale

This timescale features climate cycles that change in phase from shorter to longer over the period (Lisiecki and Raymo, 2005, Figure 4, LR04 oxygen 18 isotope proxy for average global ocean temperature). Whilst the most recent cycle peaks are roughly as warm as those at the start of the period, the cycle troughs are cooler. There was near monotonic cooling of the envelope over this timeframe, not perturbed by the onset of permanent Northern Hemisphere glaciation.

Current trend of surface temperatures in this timescale : **cooling.**

2.5 The 1 million year timescale

Ice cores range back to around 800,000 years, revealing the onset of 9 interglacials (Luthi et al., 2008, Figure 2). Each interglacial period shows relatively sharp warming over a period of several thousands of years, followed by a slow decline in temperatures over the next tens of thousands of years, until conditions cross a threshold and a glacial period begins. Each glacial period is punctuated by multiple relatively rapid and short-lived warmings (interstadials), which are thought to portray roughly 1,470 year cycles of Dansgaard-Oeschger events in Bond cycles, interspersed with Heinrich events (Alley, 2000b, Figure 12.4; Bond and Lotti, 1995; Bond et al., 1997; Bond et al., 2001; Debret et al., 2007; Fluckiger et al., 2006; McInnes, 2008).

The last glacial period began around 116,000 years ago, and terminated around 11,000 to 12,000 years ago, and had around 25 Dansgaard-Oeschger cycles in that period (NGRIP, 2004, Figure 4). The current interglacial, which began roughly 12,000 years ago appears to be more uniform than previous interglacial periods, and has shown a gradual decline in overall temperatures, as do previous interglacial periods.

Current trend of surface temperatures in this timescale : **cooling**.

2.6 The 20,000 year timescale

The Earth's climate experienced its Last Glacial Maximum at around 20,000 years ago, with deglaciation tracking the solar forcing (Clark et al., 2009) into the cooler Older Dryas period (that included Heinrich Event H1) starting 18,000 years ago (Shakun and Carlson, 2010). Bolling-Allerod warming starting around 14,500 years ago (Liu et al., 2009), followed by the sharp Northern Hemisphere-focussed cooling of the Younger Dryas period at 12,900 years ago (Broecker, 2006; Murton et al., 2010), and a sharp warming again at around 11,700 years ago (Steffensen et al. 2008, Figure 2), the Termination 1 that heralded the Holocene era. This start to the current interglacial has been compared to Termination 5 which had a similar start-

stop-start ("AMOC hysteresis" - Liu et al., 2009) behaviour (Marine Isotope Stage 11 (MIS 11)).

Since the start of the current interglacial period beginning at Termination 1, there have been several cooler periods (stadials), including what is termed the 8.2 kiloyear event (Carlson et al., 2009). The current interglacial period has been characterised by several periods of slightly warmer temperatures, at both millennial and centennial scales, but for the past 6,000 years, temperatures have generally been on the decline. The current interglacial period is expected to last for some time longer - 50,000 years (Berger and Loutre, 2002).

Current trend of surface temperatures in this timescale : **cooling**.

2.7 The last 8,000 years

Within the 8,000 year timescale, there were several significant cooling and warming events identifiable in the Arctic region of the of Late Holocene, under an overall cooling arc, according to data available from the Greenland Ice Sheet Project (GISP 2) (Figure 1). Since approximately 3,500 years BP but prior to the 20th Century, there were four warmer than average centennial-scale periods, with successively lower peaks (Figure 2). Over the 8,000 year timeframe there were approximately 10 cooling-warming cycles, with most periodicities between 500 and 800 years (Kaufman, 2009; Turney, 2005, Figure 5 for one proxy). These are variously considered to be driven by solar cycles (Jiang et al., 2005; Ogurtsov, 2010) or oceanic seesawing (Barker et al., 2009; Maslin et al., 2001; Maslin and Smart, 2009; Seidov et al., 2001; Severinghaus, 2009; Stocker and Johnsen, 2003; Swingedouw et al., 2008). Northern Hemisphere temperatures as a whole do not show the same signature of the Greenland variations in reconstructions (Christiansen and Ljungqvist 2010; Jones and Mann, 2004; Ljungqvist, 2010; Mann et al., 2008, Seppa et al., 2009), and so the underlying causes of Greenland temperature cyclicity cannot be invoked to explain anomalous global warmth in the 20th and 21st Centuries.

Temperatures in Antarctica were more stable, reflecting its climatic isolation, and experienced an overall cooling arc from about 6,000 years BP, having recovered from the 8.2 kiloyear cooling event, which shows a correlate in the Northern Hemisphere record, and can therefore be taken as global in scope. The ice core from EPICA Community at Dronning Maud Land in Antarctica published in 2006 (EDML) shows this clearly (Figure 5), and the EPICA Dome C data also indicates a similar shift (Figure 4). Studies of solar forcing suggest that the cooling trend could continue for another 23,000 years (Imbrie and Imbrie, 1980).

Current trend of surface temperatures on this timescale : **cooling**.

2.8 The 150 year timeframe

This has been the period of the instrumental record, and has shown rapid warming consistently throughout, which appears to be unprecedented. Although there is evidence of abrupt climate change in recent millenia, these events appear to have been generally sub-decadal, probably associated with changes in oceanic circulation that seem to cross some threshold (Alley, 2003; Alley, 2007; Bond et al., 1999; Broecker, 1997; Broecker, 1999), concentrated (at commencement) or localised in a particular region (Grachev and Severinghaus, 2004; Kobashi et al., 2008; Murton et al. 2010), and if there was a warming, a cooling generally came first (Steffensen et al., 2008). The last 150 years do not resemble this scenario. There appears to have been a departure from cooling trends at around 1880 (indicators point to a range between 1850 to 1910) AD, and a decadal rate of warming that appears significant on a centennial timescale.

Ocean waters in the Arctic and North Atlantic have recently been freshening (Peterson et al., 2006), but it is uncertain if this threatens a collapse of the North Atlantic Meridional Overturning Circulation (AMOC) (Bryden et al., 2005; Garzoli et al., 2010 Section 5 "Fresh Water Balance", Holmes et al., 2010, Page 2). It seems that the Atlantic circulation has changed its pattern

since the advent of the Holocene era (Negre et al., 2010), so may not be subject to the same kind of abrupt climate changes as previously, although this doesn't rule out rapid swings in future (Alley et al., 2003; Gregory et al., 2005; Lisiecki et al., 2008).

Temporally microfine "abrupt" salinity and temperature anomaly events in the Arctic relate to the natural internal variation of the Northern Atlantic Oscillation (Golubeva and Platov, 2009; Golubeva, 2010; Sundby and Drinkwater 2007), fresh water-induced, "cropped" quasi-Heinrich surges (Ziegler, 2009, pages 16, 98), which may be able to compensate for some of the land surface global warming anomaly by hemispheric oceanic thermal reorganisation (Thompson et al., 2010, Figure 1 "NH – SH"), "pumping" in phased steps driven by threshold conditions, but this periodic "negative feedback" has not interrupted the overall climb in global temperatures (Hansen et al., 2010).

Current trend of surface temperatures on this timescale : **warming**.

3. Current climatological influences

The current trend for surface temperatures is warming. The principal theory to explain this is additional Greenhouse Effect from mankind's activities - the Theory of Anthropogenic Global Warming. The IPCC's Fourth Assessment Report confirms that the core elements of this theory are robust (IPCC, 2007c, Section TS.6 "Robust findings"). Although the theory has been verified in many respects, there are also clear uncertainties, particularly in the area of the Earth's transient and equilibrium climate change response. The key question is whether the Earth, in responding to the global warming signal, can re-adjust its climate, via a set of negative (dampening) feedbacks, leading to little or no overall temperature change.

3.1 The Burden of Proof

In order to provide evidence of a causative relationship between mankind's disturbance of the Global Carbon Cycle and putative global warming, certain things have had to be established :-

3.1.1 That the near surface atmosphere and upper ocean temperatures on Earth have been rising.

3.1.2 That so-called Greenhouse Gases cause the Greenhouse Effect, and that increasing Greenhouse Gas concentrations in the atmosphere can cause added Greenhouse Effect.

3.1.3 That concentrations of Greenhouse Gases in the atmosphere are rising.

3.1.4 That mankind's activities are responsible for increasing levels of Greenhouse Gases in the atmosphere ("fingerprinting" from detection and attribution studies).

3.1.5 That there are no tertiary factors that could be causing any similar magnitude of observed global warming.

3.1.6 That there are no cyclic internal variations in the Earth system that could account for any similar temporary or sustained magnitude of observed global warming.

3.1.7 That the data are accurate.

3.1.8 That climate change (in response to global warming) is not causing negative feedbacks to counteract global warming.

3.1.9 That changes in the Global Carbon Cycle (in response to global warming) do not counteract global warming.

3.2 The Evidence

3.2.1 Global Warming is happening

Robust findings from the IPCC Fourth Assessment Report Working Group 1 established a consensus on the evidence of global warming (IPCC, 2007c, Section TS6.2.1). More detailed understanding continues to be developed, such as the effect of stratospheric water vapour on tropospheric temperatures (Solomon et al., 2010), the irreversibility of warming because of ocean heat content (Solomon et al., 2009); confirmation of strong and continuing ocean heat content (Domingues et al., 2008; Ishii and Kimoto, 2009; Levitus et al., 2009; Lyman et al., 2010) and the string of warming records being broken in the major data sets (including NASA GISS (including "Warm Stations"), NOAA NCDC, Met Office HadCRUT3, RSS and UAH).

Measures have been taken to address the lack of temperature records and proxy temperature data in the Southern Hemisphere, such as the deployment of the ARGO network of ocean monitoring buoys. However the paucity of Southern Hemisphere data does not significantly alter the conclusion that this half of the Earth's surface is also warming, in step although not in gradient, with the Northern Hemisphere (NASA GISS, 2010).

Differences between the major temperature records have been potentially ascribed to either the way that data is collectively treated and summarised (gridded) or differences in how temperatures are interpolated in the Arctic region from sparse monitoring. Despite this ongoing discussion, it is clear that all the major sources of data show synchronous regional and overall global warming of similar magnitude.

3.2.2 Greenhouse Gases cause the Greenhouse Effect

That Greenhouse Gases can absorb sunlight and re-radiate infrared (the "warming" part of the electromagnetic spectrum) is science that is roughly 150

old (Arrhenius, 1896). It's basic Physics. Barring some entirely new postulated quantum effect from a particular species of gas or particulate matter found to form part of the atmosphere, or some previously undiscovered property of the Oceans or the solid matter that forms the Earth's crust, it can be safely asserted that molecular gases with asymmetrical oscillatory modes are the cause of the Greenhouse Effect, keeping the Earth's surface warmer by around 30 degrees Celsius (IPCC, 2007e, p. 97) than it would be without an atmosphere; as they have a warming effect on their surroundings in the presence of sunlight, through their behaviour in relation to electromagnetic radiation.

3.2.3 Greenhouse Gas Concentrations rising in the atmosphere

The data work on atmospheric species (NOAA, 2010) confirms unambiguously that concentrations of carbon dioxide and other Greenhouse Gases are rising in the Earth's atmosphere. Methane concentration growth slowed (IPCC, 2007a, p. 7 (135)), but since 2007 growth in its atmospheric concentration has restarted (Rigby et al., 2008). The oxidation of methane (Boucher et al. 2009) has likely led to an increase in stratospheric water vapour (IPCC, 2007a, p. 24 (152); Myhre et al., 2007). Ozone levels in the troposphere respond to methane concentrations (Fiore et al., 2008), and have also been rising (IPCC, 2007a, p. 3 (131)). Modifications to the Montreal Protocol contributed to restraining growth in halocarbons, chemistry with high Global Warming Potential.

3.2.4 Fingerprinting Humankind

In detection and attribution studies, progress has been made in clearly "fingerprinting" humankind's activities as the cause of rising concentrations of atmospheric Greenhouse Gases. The work on the ratios of carbon isotope species has shown that fossil fuel-derived carbon is increasing in the atmosphere. When fossil fuels are burned, they oxidate, and a clear signal of oxygen depletion in the atmosphere has been detected (IPCC, 2007a, Figure 2.3), which outstrips possible effects from deforestation, or the any mass

death of photosynthetic life on land, or in the oceans, due to acidification from increased atmospheric carbon dioxide.

3.2.5 Significant External Forcings

In any empirical research that seeks establish the cause or causes of an effect, it is always necessary to consider tertiary factors to the hypothesis - other possible causes that may better explain the outcome. Also, it is necessary to consider indirect causation - that there is a precursor, a factor that causes the cause being considered.

Some influences on temperature in the Earth system are considered to be "external" to the normal climate cycles, and some as inherent "internal" variation (see further down).

3.2.5.1 Radiative Forcing

As a measure of the warming effect at the Earth's surface, radiative forcing is more "readily calculable" (IPCC, 2007a, p. 5 (133)) than overall climate sensitivity. The "forces for warming" arise from the composition of the atmosphere, influences from the chemical species, chemical reactions and airborne particulate matter (aerosols) such as dust and ash (Lohmann et al. 2010). There is discussion about whether some effects should be considered feedbacks or primary forcings (IPCC, 2007a, p. 153). There are also complex discussions about the sign of the influence, whether warming or cooling, at different heights in the atmosphere and various regional locations (Alterskaer et al., 2010). One of thorniest issues appears to be whether the forcings should be calculated in a way that discounts (Alterskjaer, 2010) or accounts (Hansen et al., 2005) for the short-term stratospheric response.

There is much agreement that the rapid increase in carbon dioxide in the atmosphere acts as a pulse, an almost instantaneous (in geological timescales) compositional change in the atmosphere and is modelled as such (IPCC, 2007d). There are still some areas of "low" scientific understanding

(IPCC, 2007a, Executive Summary), but aside from studies on clouds, these are for chemistry where influence on warming is anticipated to be minor.

One key area of study is the various effects of industrial aerosols, particulate matter and chemical species produced by humankind's activities such as burning fossil fuels for transport, electricity generation and manufacturing; which go on to reside and react at various regions and levels of the atmosphere (Hansen et al., 2005, p. 35), with various warming or cooling impacts. An example is the direct aerosol effect, the scattering and absorption of incoming solar electromagnetic radiation by airborne particulate matter. Scattering leads to less sunlight reaching the surface of the Earth, and is the key factor in what has been named "Global Dimming", an effect that has protected the Earth from some global warming (Ramanathan and Feng, 2009). Dust has apparently been identified as a coolant (Mahowald et al., 2010), or has a mixed effect (Kok, 2010). The differences in the temperature records of the Northern and Southern Hemisphere can be partly explained by such studies.

High levels of aerosol in both the stratosphere and the troposphere are the major factors in the net negative radiative forcing at the surface of the Earth (IPCC, 2007a, p. 132, Executive Summary, p. 208, Section 2.9.5), however, the evidence is that Earth is as a whole still warming (IPCC, 2007b, Sections 3.2, 3.8), perhaps exponentially (IPCC, 2007b, Tables 3.2 and 3.3), which must be attributable to the tropospheric radiative forcings summing to a positive, warming value (IPCC, 2007a, p. 205, Section 2.9.2).

If the atmosphere, and the oceans, with which it interacts, were not in constant motion, and if the climate response didn't include some additional warming (cooling) as positive (negative) feedback, the radiative forcing calculations could lead to straight-forward projections of global warming, but the real world is more complicated than just considering a simple well-mixed atmosphere in stasis on a non-rotating Earth. However, radiative forcing of atmospheric components, expressed in Watts per square metre, helps tease out the relative strength of various unknowns, such as the correct magnitude

and sign of the warming influence of solar irradiance change in various parts of the electromagnetic radiation spectrum (Hansen et al., 2005 paragraph 8; Haigh et al., 2010).

3.2.5.2 Volcanic Eruptions

The Mount Pinatubo volcanic eruption in June 1991 afforded a prime opportunity to study the effects of volcanic aerosols in the atmosphere. The analysis showed an intense, but short-lived (less than 5 years), global cooling effect (IPCC, 2007a, pp. 132, 137, 142, 193). Regular volcanic activity does emit carbon dioxide (and methane too by disruption of sequestered fossilised organic matter) into the atmosphere from the Earth's crust (Hards, 2005), but measurements of carbon dioxide levels after eruptions do not show any great rise in atmospheric concentrations (NOAA, 2010). So, recent global warming cannot be attributed to volcanism.

3.2.5.3 Solar Irradiance Change

Obviously, the Sun is the primary cause of keeping the Earth's surface warm, but the rate of recent rise in Earth's surface temperature does not correlate significantly with changes in solar irradiance output (Lockwood and Frohlich, 2008). Changes in solar activity are considered to account for a small proportion of measured global warming over the last 100 years, but their contribution to global warming of the past 20 – 50 years is vanishing (Ammann et al., 2007; Duffy et al., 2009; Meehl et al., 2004, Lean, 2010; Lockwood, 2010). Solar side-effects such as the solar wind, and its effects on cosmic rays, and their purported effects on the atmosphere and its clouds have not been shown to have any significant effect (Skeptical Science, 2010). There is strong evidence from paleoclimatology that change in solar insolation due to the precession and tilt of the Earth's axis, and its orbital progression around the Sun have strongly influenced climate cycles in the deep past (see Section 2). But then, as now, change in solar output and insolation have been cyclic or periodic, with quasi-sinusoidal change, whereas current global warming appears to be exponential and unidirectional. Episodic alterations in

the spectral distribution of solar output during its short-term 11-year cycles may play a part in variations of the temperature of the near-surface Earth (Haigh et al., 2010), but again, these would be expected to crest and dip on the whole, whereas current global warming appears to be a sustained positive phase change.

3.2.5.4 Land Use Change

Deforestation is said to account for something in the region of 15% of net anthropogenic Greenhouse Gas emissions to air (van der Werf et al., 2009), and so, although it will have long-term, possibly permanent, effects on Earth's climate, it cannot account for the bulk of recent warming. Nitrous Oxide is a Greenhouse Gas whose rising emissions are attributable to changes in agriculture (IPCC, 2007a), but it has only roughly a third of the effect of methane (IPCC, 2007a, Fig 2.21). Soil erosion and desiccation from agricultural intensification has led to a breakdown in the carbon cycle - less carbon dioxide is sequestered in soils, but the scale of emissions increase cannot account for the levels of warming being measured.

Widescale deforestation and the development of agriculture have been suggested to explain the extremely unusual and stable nature of the Holocene era (Ruddiman et al., 2010), in that the temperatures have not reduced rapidly after the warming spike at the end of the Last Glacial Maximum as they did in previous glacial Terminations, as seen in the ice core records (see Section 2). Global warming has reversed the general cooling trend of the last 6,000 years in the last 150 years or so, which just happens to coincide with vast increases in agricultural production and the exploitation of timber, aided by the use of fossil fuels for energy; but the fossil fuel emissions are by far the largest factor.

3.2.5.5 Rapid warming – alternative mechanisms

There have been several alternative mechanisms proposed for periods of rapid global warming in Earth history, one of which being the mass emission

of carbon dioxide and methane during the collision of tectonic plates, triggering ocean anoxia and emissions of warming hydrogen sulphide and mass extinction (Ward, 2006). While there is evidence of anoxic events taking place currently, these seem to be associated with run-off from agricultural and toxic waste into the oceans. There is no evidence of the "ocean conveyor belt" (Lozier, 2010) undergoing major alterations which could allow explanations of large quantities of heat or methane being released to the atmosphere from ocean depths. Although there is evidence of rising methane concentrations in the atmosphere, and methane emissions are causing concern in the melting permafrost and tundra of the Arctic region, these are considered to be an effect of global warming rather than a cause, unlike ancient events (see Section 2).

The current warming can be attributed with high levels of confidence to radiative forcing. Confirmation comes from a wide variety of sources, for example, consideration of the Diurnal Temperature Range, stratospheric cooling, hemispheric and zonal differences in warming, and analysis of extremes and frequencies of extremes in weather.

3.2.6 Significant Internal Variability

The magnitude of the swings in internal variability in the climate can sometimes overwhelm the signal from global warming. However, variability cannot be equated with a trend. The aim of studies into variation must be to establish whether the changes are a result of global warming, or a cause. Here, the most significant internal variability factors are considered.

3.2.6.1 Oscillations - Climate Cycles

The air pressure oscillations and their climatic teleconnections are a significant feature of the Earth system, and it is important to be clear that recent global warming is not merely an upswing in one or more of these climate cycles. There is evidence of multi-decadal waves patterns, but

oscillations would need to have a centennial-scale long cycle, or longer, to explain the current warming period.

When analysing climate oscillations it is important not to be misled by anomalies in the data series, which may be due to unrelated factors, or even instrument errors (see "Data Correction" section below). For example, the cooling phase between the late 1960s and early 1970s has been associated with a "Great Salinity Anomaly" in the North Atlantic – which could have been caused by meltdown in the polar region (Peterson et al., 2006, Figure 4; Thompson et al., 2010). Ongoing changes in Arctic precipitation and ice pack could be responsible for future short-term cooling episodes (Dickson et al., 2000, Figure 7; Miller et al., 2010, p. 21 (1699); NSIDC, 2008; Seo et al., 2010).

There is evidence of change in the climate oscillations as measured by their indices over timescales of decades - the patterns of the anomalies have changed as well as the trends (Hurrell et al, 2003, NCAR, 2010; NOAA Data, 2010). This suggests the climate oscillations are being altered by global warming.

There is an inherent problem in trying to assess the indices of the oscillations, as the "base" period on which the calculations of anomalies in the wave patterns are made may not represent a time of stability, as is suggested by the indices datasets themselves (Hurrell and Deser, 2009; NCAR, 2010). The mean of a moving target may not represent a suitable measure from which to judge movement overall.

The underlying trends for oscillations seen in the 1980s to 1990s have not persisted (Osborn, 2010), so some multi-decadal cyclicity could be a component of what is happening, or other factors may be coming into play, such as one-way-only threshold-reliant readjustment of the vertical layers of the atmosphere, or the transport between ocean basins. The evolution of the ENSO could corroborate this (Ashok et al., 2007).

Transformation arithmetic is used to calculate the "normal" patterns of oscillation in the climate of the ocean basins (Empirical Orthogonal Functions (EOF) or Principal Components Analysis (PCA)), and the reported indices are therefore modulation anomalies from these "carrier" wave patterns. However, if the basic modality of the oscillations are themselves subject to change, the approach breaks down at the first assumption (Kellie-Smith, 2010, 4.5 "Conclusion"). New ways to subtract the ENSO signal from global temperatures are being developed (Chen et al., 2008a, p. 5 "contaminates", Chen et al. 2008b).

At present there is no contender for an oscillation that correlates either its positive or negative phase index, or both, with the global warming trend. A case in point is the Arctic Oscillation (AO), which showed a positive trend in its index throughout several decades, and suggested a correlation with global warming, but has now gone into a severe negative phase, even as 2010 is expected to be the warmest year in the instrumental record.

Combining the indices of the oscillations does not show a general trend, as they are all, to some extent, co-varying with time lags, which would tend to cancel them out. However, the ENSO oscillation, and polar modes including the North Atlantic Oscillation (NAO) seem to lead or greatly influence the others, and could be considered real internal variation.

3.2.6.2 Circulations

There has been some evidence that the ocean circulation patterns are changing in response to global warming (Sherwood et al., 2011; Williams and Grotoli, 2010). However, although highly variable, the strength of the Atlantic Meridional Overturning Circulation (AMOC) does not appear to be suffering significant reduction (RAPID-WATCH, 2010).

As regards air mass circulation, coincident with unusually low indices in the Arctic Oscillation (AO) in recent years, displacement of the jet streams have been implicated in "blocking" events, preventing the usual waves of

propagation of anti-cyclones in the Northern Hemisphere (see "Mixed Layers" section below; WMO, 2010). Impacts cited in the popular press included the severe winter of 2009/2010, the extreme heat in Russia in summer 2010 and catastrophic flooding in Pakistan in the same season (Woollings et al., 2010). The IPCC Fourth Assessment states that blocking is trending in step with global warming, but only in the North Pacific in connection with La Nina (IPCC, 2007b, Section 3.5.4 "Blocking"). Recent events suggest it could become more general.

3.2.6.3 Mixed Layers

There is evidence that the tropopause has changed its height (Santer et al., 2003; Schmidt et al., 2008), most likely as a result of global warming, and clearly has implications for planetary waves at the troposphere-stratosphere boundary, jet streams and the annular modes of oscillation at the poles (IPCC, 2007b, Section 3.5.6).

The mixed layer between the atmosphere and the ocean has been showing the effects of ocean warming (Domingues, 2008), and the intensity of tropical hurricanes and other storms near the Equator has been shown to have increased owing to higher sea surface temperatures (Elsner et al. 2008).

These changes all have implications for the near-Earth surface temperatures, but it is determined that they are feedbacks, not causes.

3.2.7 Data Correction

Problems with global temperature data sets relate to a number of issues, including changes in technology, instrument bias and alteration in human systems of data collection. Anyone attempting to perform statistical modelling of climate systems based on the data sets will need to first iron out the data wrinkles, or else their analysis risks being unsound. One example is that of an apparent abrupt dip in sea surface temperatures in the period between 1940 and 1950, which it turns out can be explained as a data problem (Thompson

et al., 2008). By using a simple arithmetic technique of subtracting oscillation anomalies (indices) and other well-known factors from the overall temperature records, it has been shown that the effect can be attributed to more measurements being done with one method than another. Another example of data correction is when Dr John Christy and Dr Roy Spencer famously had to retract claims regarding global warming when it was discovered that there were bias errors in satellite monitoring data, when in fact there are no significant difference between the major data sets when adjusted (Thorne et al., 2010).

3.2.8 Climate Feedbacks

There is ongoing research into cooling (negative) feedbacks in the climate system, and whether they could constrain the warming effect of increased concentrations of atmospheric greenhouse gases. If these effects are temporary, they could only offer a short-term reprieve. There has been much discussion around the "fertilisation effect" of increased atmospheric carbon dioxide, and evidence has been found to support that (Lewis et al., 2009), although this could be overwhelmed by future climate changes, including in rainfall patterns and drought (Dai, 2010).

There is some suggestion that global warming, since it leads to a higher level of water vapour sustainable in the atmosphere, could lead to enhanced cloud cover of forms that show increased cooling albedo - as long as this compensates for their added Greenhouse Effect. There remain considerable uncertainties about the role of clouds under current conditions of sharp global warming (IPCC, 2007c, Section TS6.2.1; IPCC, 2007b, Section 3 3.4).

Most feedbacks are found to be positive (warming), enhancing and amplifying global warming. The sensitivity of the climate - the exact level of the full-term warming response to the changes in atmospheric composition - remains uncertain, but is known to be significant (IPCC, 2007d).

3.2.9 Carbon Cycle Feedbacks and consideration of Paleo-Analogies

Given that Anthropogenic Global Warming, as proposed, would disturb the Global Carbon Cycle, possible responses have been assessed to see if they could counteract the warming by increasing the carbon pump or carbon sink effect.

3.2.9.1 Evidence of current Global Carbon Cycle change

There are uncertainties in how the Carbon Cycle will respond (IPCC, 2007f, Section 7.3; IPCC, 2007d, Section 10.4). There are some indications that the "biological pump" of the ocean that draws carbon dioxide down from the atmosphere may be compromised (Boyce et al., 2010). However, it is also possible that for now, the oceans and land plants (although not the soils, perhaps) are taking up the same fraction of carbon dioxide from the atmosphere as ever, meaning more carbon dioxide poached from the air in total (Knorr, 2009; Sarmiento and Gruber, 2002, Figure 3). These changes are best explained as being caused by global warming. Changes in the slow geological sequestration components of the Carbon Cycle are probably not measurable.

3.2.9.2 Paleo-Analogies

It is instructive to look back into the deep past to try to establish how the Global Carbon Cycle initially adjusted to, and then re-adjusted atmospheric carbon dioxide levels. These include the sharp warming occurred at the boundary of the Paleocene and Eocene geological eras (PETM) (Kopp et al., 2007), the mid-Eocene (Bijl et al., 2010), Termination V, MIS 11 (Bowen, 2010) and the mid-Pliocene (Ravelo et al., 2009). None of the periods so far considered can be a perfect analogy, because unfolding conditions are highly anomalous, including a very high rate of atmospheric carbon dioxide accumulation.

4. Conclusions

Recent global warming is a real effect (Thorne et al., 2010), and the only significant correlating relationship is with anthropogenic alteration of the atmosphere, as none of the alternative hypotheses could provide the magnitude or signature of the changes observed. The net emissions to air of greenhouse gases from anthropogenic sources, the side-effects of which include the ejection of aerosols, are altering the net radiative forcing. Having established confidently this is the reason for sustained and increasing global warming, it becomes justifiable to deduct the effects of internal variability and episodic external forcings such as volcanic eruptions from the temperature record in order to reveal the global warming trend. Correcting for data problems, compensating for volcanic episodes and deducting the indices of the major climate oscillations from the temperature record, the largest instantaneous modulations, vastly improves perception of the underlying warming signal (Thompson et al., 2009, Figure 12).

Further work on quantifying the change in climate oscillations could lead to new indices that could be applied to further smooth out the saw tooth nature of the progression of the temperature sensitivity of the climate. It remains for the climate change research community to collectively agree how the "resolved" datasets should be produced and published, showing the "smoother" baseline global warming pulse for public and policy use.

Figures

Greenland Ice Core GISP2

ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/greenland/summit/gisp2/isotopes/gisp2_temp_accum_alley2000.txt

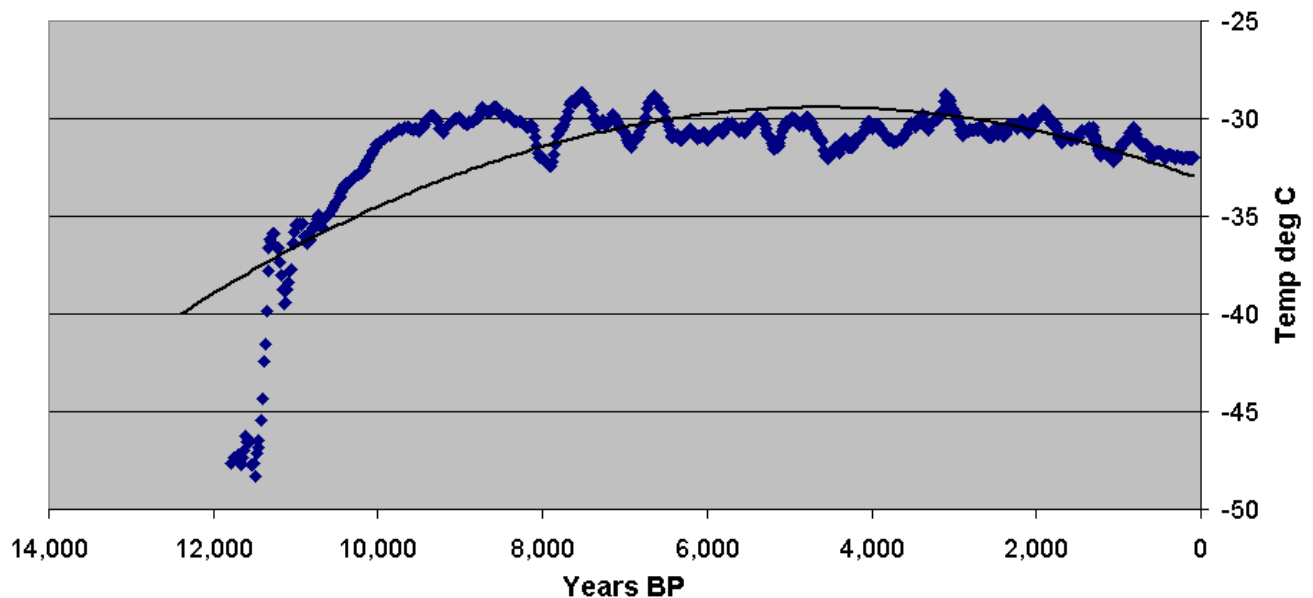


Figure 1

GISP2 Greenland Ice Sheet Project 2 Ice Core Data (Alley, 2000a; Alley, 2004; Cuffey and Clow, 1997).

Raw data points with a second order polynomial trend line added by Excel, covering data from approximately 12,000 years before present up until approximately 200 years before present to prevent the inclusion of the anomalously warm recent period. The second order polynomial trend line has been added automatically, merely to indicate the most likely point of temperature maximum but does not represent any precision in calculation.

Greenland Ice Core GISP2

ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/greenland/summit/gisp2/isotopes/gisp2_temp_accum_alley2000.txt

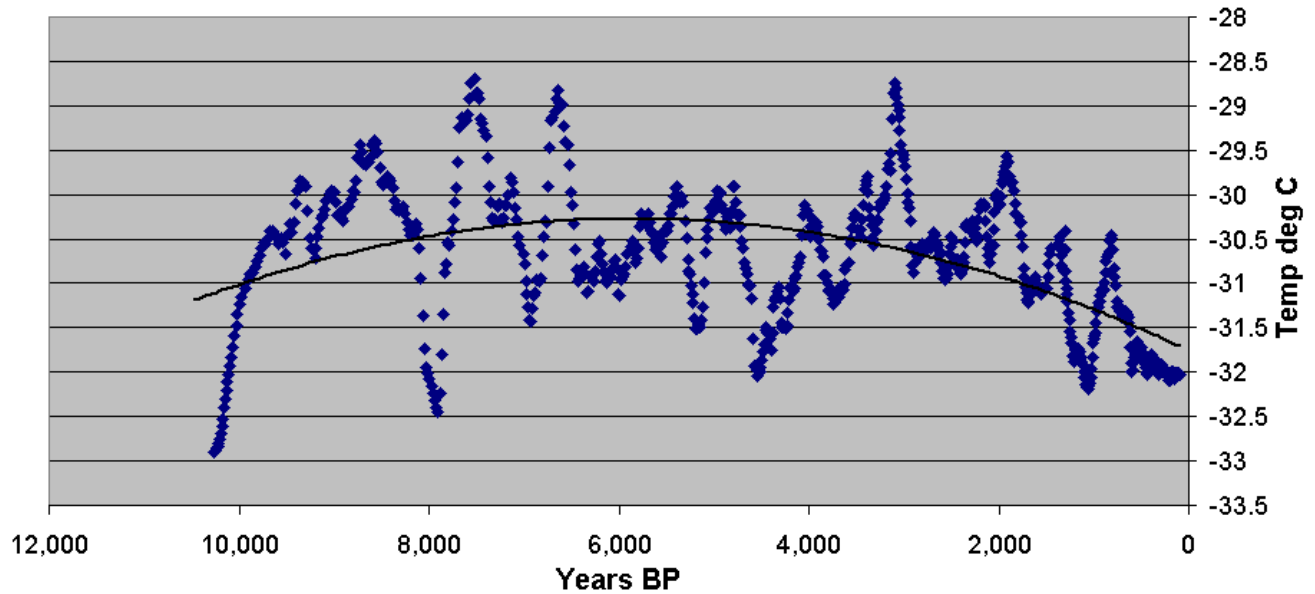


Figure 2

GISP2 Greenland Ice Sheet Project 2 Ice Core Data (Alley, 2000a; Alley, 2004; Cuffey and Clow, 1997).

Raw data points with a second order polynomial trend line added by Excel, covering data from approximately 10,500 years before present up until approximately 200 years before present to prevent the inclusion of the anomalously warm recent period. The second order polynomial trend line has been added automatically, merely to indicate the most likely point of temperature maximum but does not represent any precision in calculation.

Vostok Ice Core Data

<http://cdiac.ornl.gov/ftp/trends/temp/vostok/vostok.1999.temp.dat>

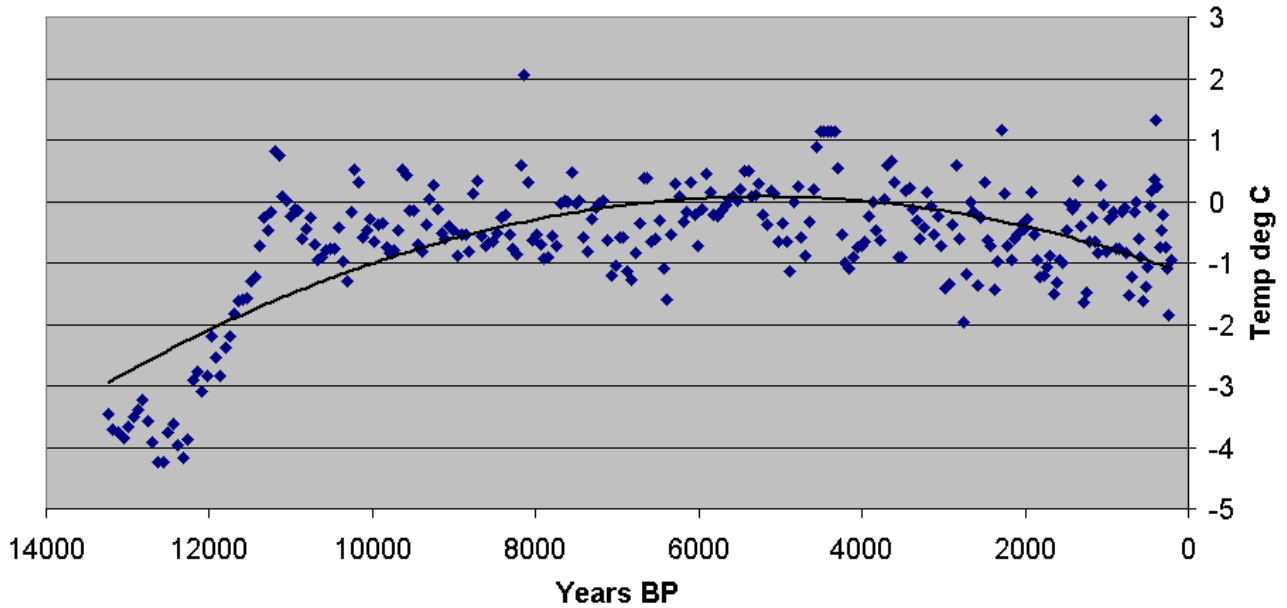


Figure 3

Lake Vostok Ice Core Data (Jouzel et al., 1987; Jouzel et al., 1993; Jouzel et al., 1996; Petit et al., 1999).

Raw data points with a second order polynomial trend line added by Excel, covering data from approximately 13,500 years before present up until approximately 200 years before present to prevent the inclusion of the anomalously warm recent period. The second order polynomial trend line has been added automatically, merely to indicate the most likely point of temperature maximum but does not represent any precision in calculation.

EPICA DOME C Ice Core

ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/epica_domec/edc3deutemp2007.txt

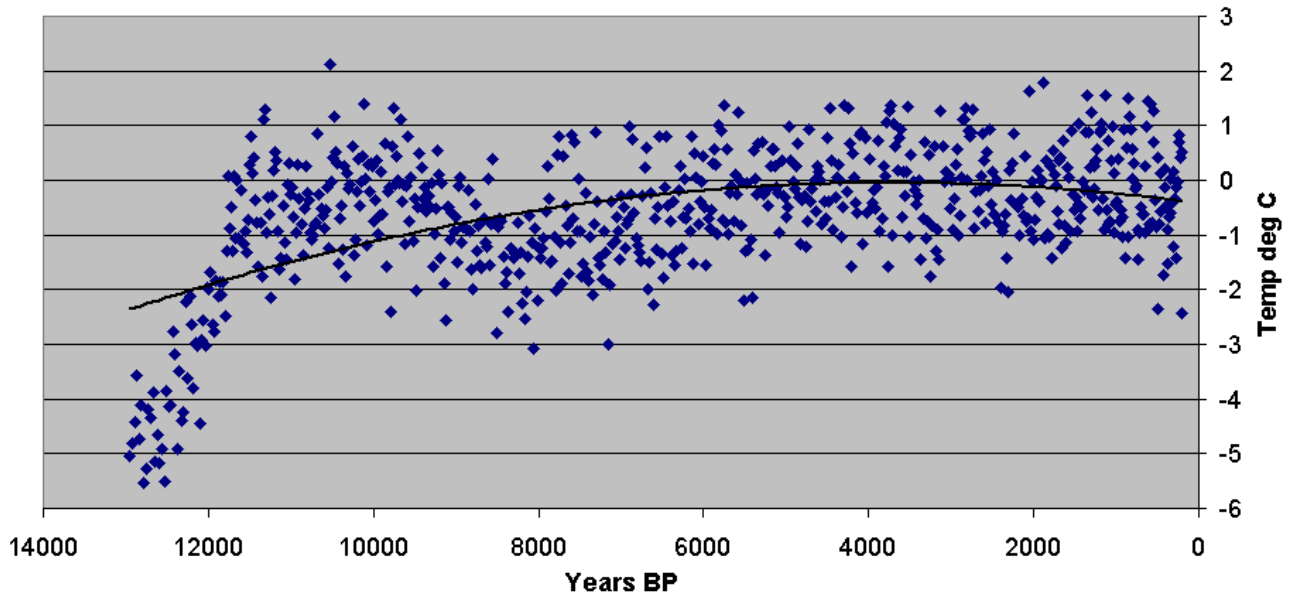


Figure 4

EPICA Community Dome C Ice Core Data (Jouzel et al., 2007).

Raw data points with a second order polynomial trend line added by Excel, covering data from approximately 13,000 years before present up until approximately 200 years before present to prevent the inclusion of the anomalously warm recent period. The second order polynomial trend line has been added automatically, merely to indicate the most likely point of temperature maximum but does not represent any precision in calculation.

EDML 2006 Ice Core

<http://doi.pangaea.de/10.1594/PANGAEA.552270>

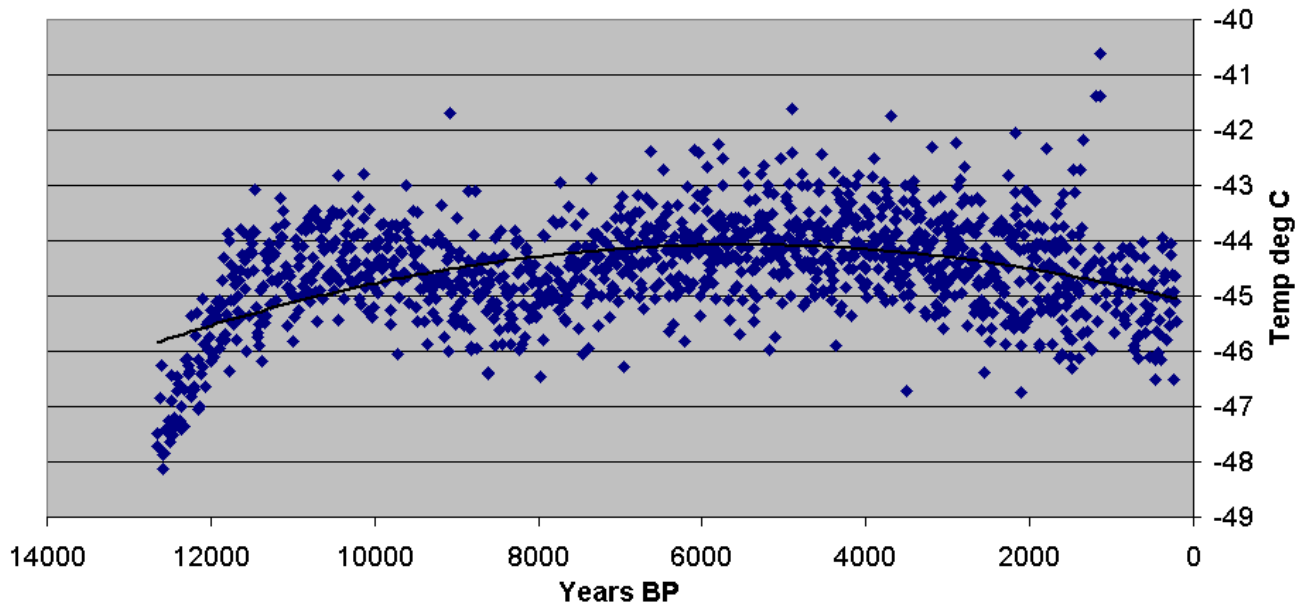


Figure 5

EPICA Community Dronning Maud Land Ice Core Data (EPICA Community, 2006).

Raw data points with a second order polynomial trend line added by Excel, covering data from approximately 12,500 years before present up until approximately 200 years before present to prevent the inclusion of the anomalously warm recent period. The second order polynomial trend line has been added automatically, merely to indicate the most likely point of temperature maximum but does not represent any precision in calculation.

Abbreviations

ya = years ago, relative to 1950
BP = Before Present, relative to 1950
IPCC = Intergovernmental Panel on Climate Change
AR4 = IPCC Fourth Assessment Report
WG1 = IPCC Working Group 1

Glossary

LLGHG = Long-Lived Greenhouse Gas
ENSO = El Niño Southern Oscillation

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