

# Portents of 21st Century Global Warming

Extreme GHG and temperature rise rates question linear climate projections

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Theme: [Environment](#)

In-depth Report: [Climate Change](#)

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*"We will be in a position where we set off an irreversible chain reaction beyond human control that will most likely lead to the end of our civilization as we know it"...*

*"Now we probably don't even have a future anymore, because that future was sold so that a small number of people could make unimaginable amounts of money. It was stolen from us every time you said that the sky was the limit, and that you only live once. **You lied to us.** You gave us false hope. You told us that the future was something to look forward to. And the saddest thing is that most children are not even aware of the fate that awaits us. We will not understand it until it's too late. And yet we are the lucky ones. Those who will be affected the hardest are already suffering the consequences. But their voices are not heard." [Greta Thunberg](#)*

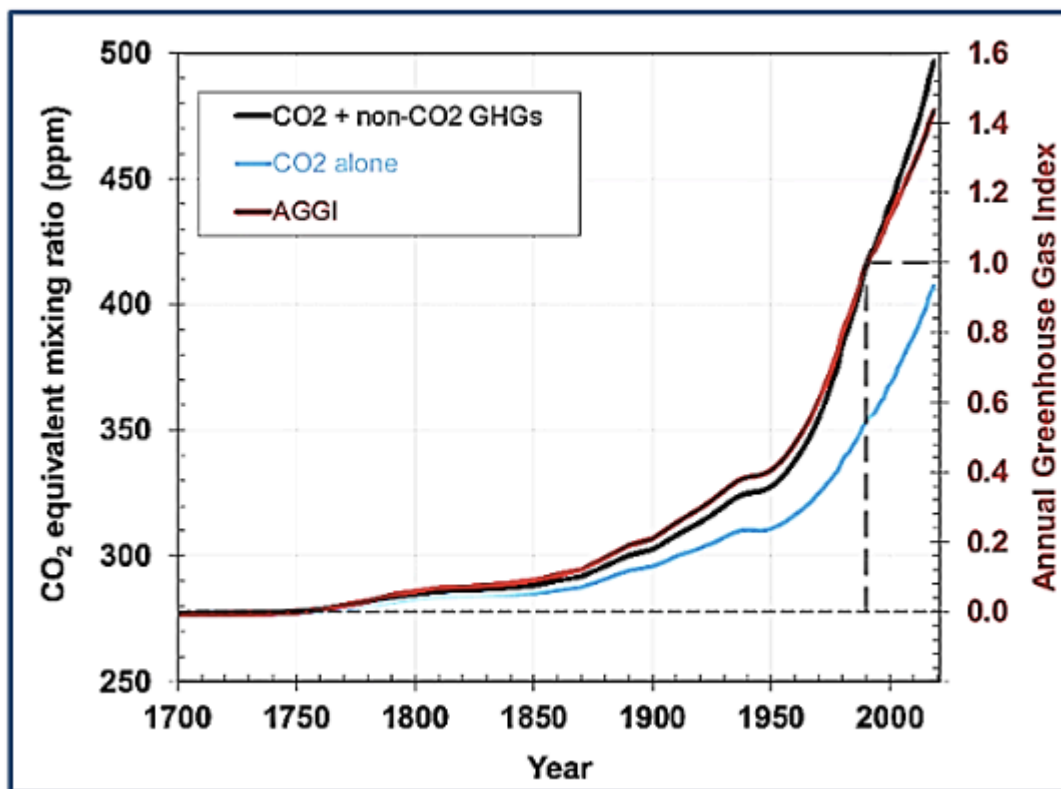
## Introduction

The extreme GHG and temperature rise rates since the mid-1970<sup>th</sup> raise questions over [linear climate projections](#) for the 21<sup>st</sup> century and beyond. Under a rise of CO<sub>2</sub>-equivalent reaching +500 ppm and [3.0Wm<sup>-2</sup>](#) relative to 1750, the current rise rates of CO<sub>2</sub> by [2.86 ppm per](#) and recent global temperature rise rate ([0.15-0.20°C per decade](#)) since 1975 are leading to an abrupt [shift in state](#) of the terrestrial climate and the biosphere. By mid-21<sup>st</sup> century at >750 ppm CO<sub>2</sub>-e climate tipping points indicated by [Lenton et al. 2008](#) and [Schellnhuber 2009](#) are likely to be crossed. Melting of the Greenland and Antarctic ice sheets has increased by a [factor of more than 5](#) since 1979-1990. As the ice sheets and sea ice melt the [albedo flip](#) between reflective ice surfaces and dark infrared-absorbing water results in significant increase of radiative forcing and complete removal of Arctic sea ice would result in a forcing of about 0.7 Wm<sup>-2</sup> ([Hudson, 2011](#)). The confluence of climate events, including a breach of the circum-Arctic jet stream boundary and a polarward migration of [climate zones](#) at a rate of [56-111 km per decade](#), induce world-wide extreme weather events including [bushfires](#), [methane release](#) from Arctic permafrost and sediments. For a [climate sensitivity of 3±1.5°C](#) per doubling of atmospheric CO<sub>2</sub>, global warming has potentially reached between +2°C to +3°C above mean pre-industrial temperatures at a rate exceeding the fastest growth rate over the last [55 million years](#). As ice melt water flow into the oceans temperature polarities between warming continents and

cooling tracts of ocean would further intensify extreme weather events under non-linear climate trajectories. The enrichment of the atmosphere in GHG, constituting a shift in state of the terrestrial climate, is predicted to delay the onset of the next glacial state by some [50,000 years](#).

### A. GHG and temperature rise

The paleoclimate record suggests that no event since 55 million years ago, the Paleocene-Eocene Thermal Maximum ([PETM](#)), when global temperatures rose by [more than +5 to +8°C](#) over a period of [~20,000](#) years, with a subsequent warming period of up to 200,000 years, has been as extreme as atmospheric disruption since the onset of the industrial age about 1750 AD (the Anthropocene), accelerating since 1975. During this period greenhouse gas levels have risen from [~280 ppm](#) to above [>410 ppm](#) and to [496ppm CO<sub>2</sub>-equivalent](#) (Figure 1), the increase of CO<sub>2</sub> reaching near-47 percent above the original atmospheric concentration. However linear climate change [projections](#) are rare in the recent climate history (Figure 2) and linear future climate projections may not account for the effects of [amplifying feedbacks](#) from land and oceans. Given an Anthropocene warming rate faster by [~X200](#) times than the PETM (Figure 3), linear warming trajectories such as are projected by the [IPCC](#) may overlook punctuated tipping points, transient reversals and [stadial](#) events.



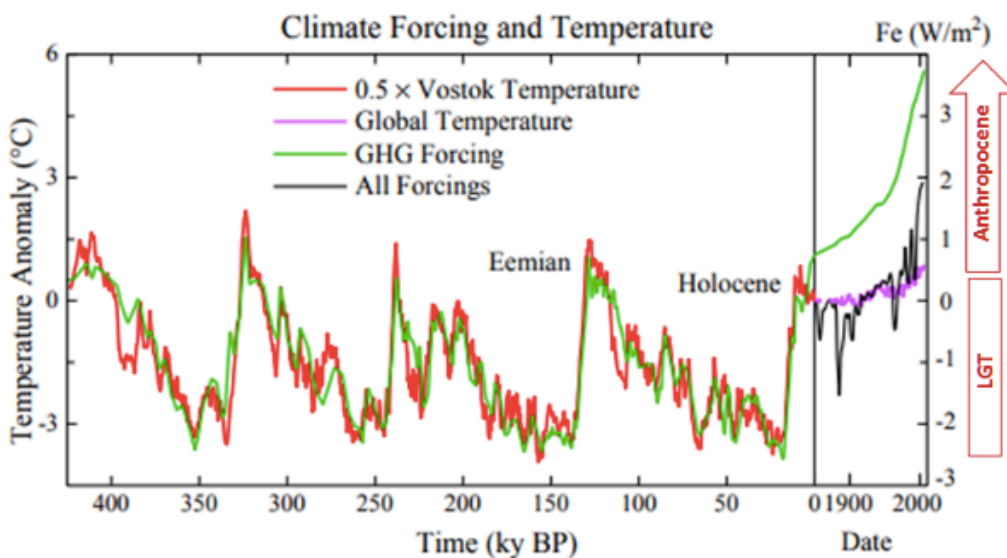
**Figure 1.** Growth of CO<sub>2</sub>-equivalent level and the annual greenhouse gas Index (AGGI[1]).

Measurements of CO<sub>2</sub> to the 1950s are from ([Keeling et al., 2008](#)) and from air trapped in ice and snow above glaciers. Equivalent CO<sub>2</sub> amounts (in ppm) are derived from the relationship between CO<sub>2</sub> concentrations and radiative forcing from all [long-lived greenhouse gases](#).

According to [NOAA](#) GHG forcing in 2018 has reached 3.101 Wm<sup>-2</sup> relative to 1750

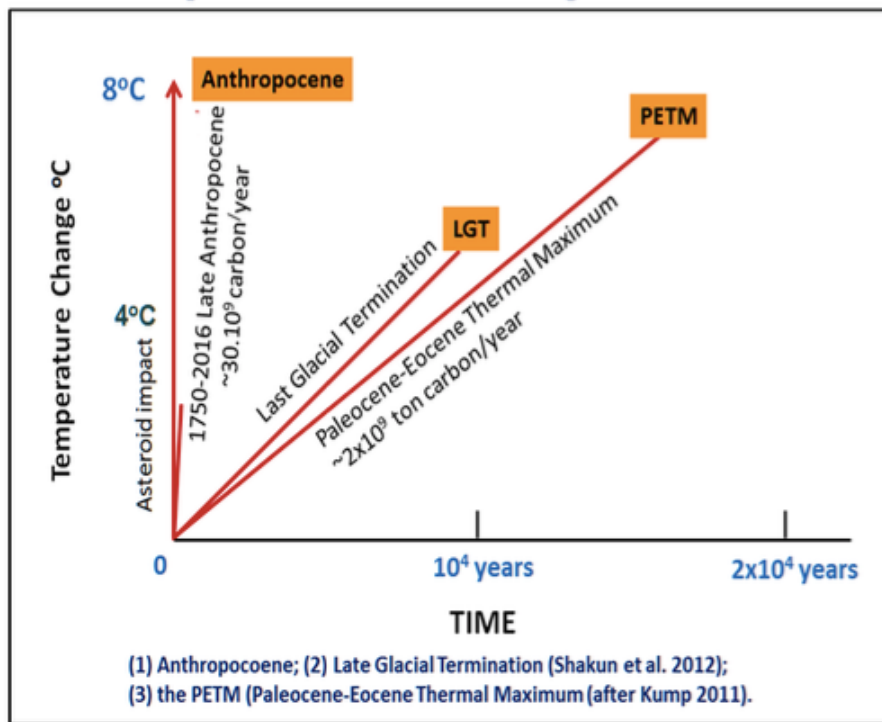
( $\text{CO}_2=2.044\text{Wm}^{-2}$ ;  $\text{CH}_4= 0.512 \text{ Wm}^{-2}$ ;  $\text{N}_2\text{O} = 0.199\text{Wm}^{-2}$ ;  $\text{CFCs} = 0.219\text{Wm}^{-2}$ ) with a  $\text{CO}_2$ -equivalent of 492 ppm (Figure 1). The rise in GHG forcing during the Anthropocene since about 1800 AD, intensifying since 1900 AD and sharply accelerating since about 1975, has induced a mean of  $\sim 1.5^\circ\text{C}$  over the continents above pre-industrial temperature, or  $>2.0^\circ\text{C}$  when the [masking role of aerosols](#) is discounted, implying further warming is still in store.

According to [Hansen et al. 2008](#) the rise in radiative forcing during the Last Glacial Termination (LGT  $-18,000$   $-11,000$  years BP), associated with enhancing feedbacks, has driven GHG radiative forcing by approximately  $\sim 3.0 \text{ Wm}^{-2}$  and a mean global temperature rise of  $\sim 4.5^\circ\text{C}$  (Figure 2), or, i.e. of similar order as the Anthropocene rise since about 1900. However the latter has been reached within a time frame at least X30 times shorter than the LGT, underpinning the extreme nature of current global warming.



**Figure 2** ([Hansen et al. 2008](#)). Glacial-temperature and GHG forcing for the last 420,000 years based on the Vostok ice core, with the time scale expanded for the Anthropocene. The ratio of temperature and forcing scales is  $1.5^\circ\text{C}$  per  $1 \text{ W/m}^2$ . The temperature scale gives the expected equilibrium response to GHG change including slow feedback surface albedo change. Modern forcings include human-made aerosols, volcanic aerosols and solar irradiance.

The  $\text{CO}_2$  equivalent levels and radiative forcing levels constitute a rise from Holocene levels ( $\sim 280 \text{ ppm CO}_2$ ) to  $>410 \text{ ppm}$  compared with Miocene-like levels ([300-600 ppm  \$\text{CO}\_2\$](#) ), at a rate reaching [2 to 3 ppm/year](#), within a century or so, driving the fastest temperature rise rate recorded since 55 million years ago (Figure 3).



**Figure 3.** A comparison between rates of mean global temperature rise during: (1) the last Glacial Termination (after [Shakun et al. 2012](#)); (2) the PETM (Paleocene-Eocene Thermal Maximum, after [Kump 2011](#)); (3) the late Anthropocene (1750–2016), and (4) an asteroid impact. In the latter instance temperature due to CO<sub>2</sub> rise would lag by some weeks or months behind aerosol-induced cooling

Considering the transient mitigating albedo effects of clouds, seasonal land surface albedo, ice albedo, atmospheric [aerosols](#) including [sulphur dioxide](#) and nitrate, [the potential rise of land temperature could have reached -0.4 to -0.9 Wm<sup>-2</sup>](#) in [2018](#), masking approximately 0.6 to 1.3°C potential warming once the short lived aerosol effect is [abruptly reduced](#).

## B. Accelerated melting of the ice sheets

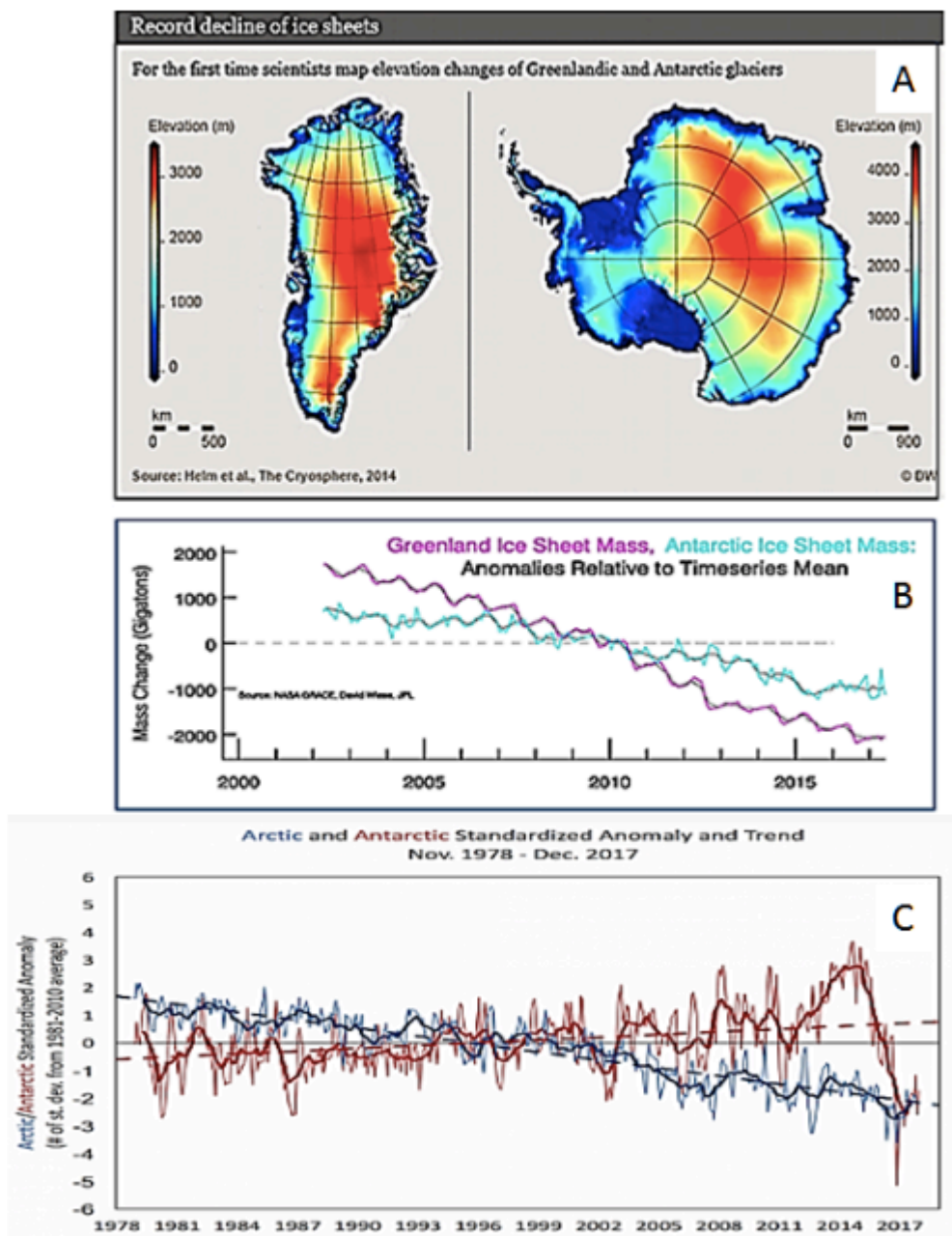
The fast rate of the Anthropocene temperature rise compared to the LGT and PETM (Figure 3) ensues in differences in terms of the adaptation of flora and fauna to new conditions. The shift in state of the Earth’s climate is most acutely manifested in the poles, where warming leads to weakening of the jet stream boundaries which are breached by outflow of cold air fronts, such as the recent “[Beast from the East](#)” event, and penetration of [warm air masses](#).

As the poles keep warming, to date by a mean of [~2.3°C](#), the shrinking of the ice sheets per year has accelerated by a factor of more than [six fold](#) (Figure 4). Warming of the Arctic is driven by the ice-water albedo flip, where dark sea-water absorbing solar energy alternates with high-albedo ice and snow, and by the weakening of the polar boundary and jet stream.

**Greenland.** The threshold of collapse of the Greenland ice sheet, retarded by [hysteresis](#)[2], is estimated in the range of [400-560 ppm](#) CO<sub>2</sub>, already transgressed at the current 496 ppm CO<sub>2equivalent</sub> (Figure 4). The [Greenland](#) mass loss increased from 41 ± 17 Gt/yr in 1990–2000, to 187 ± 17 Gt/yr in 2000–2010, to 286 ± 20 Gt/yr in 2010–2018, or six fold since the 1980s, or 80 ± 6 Gt/yr per decade, on average.

**Antarctica.** The greenhouse gas level and temperature conditions under which the East

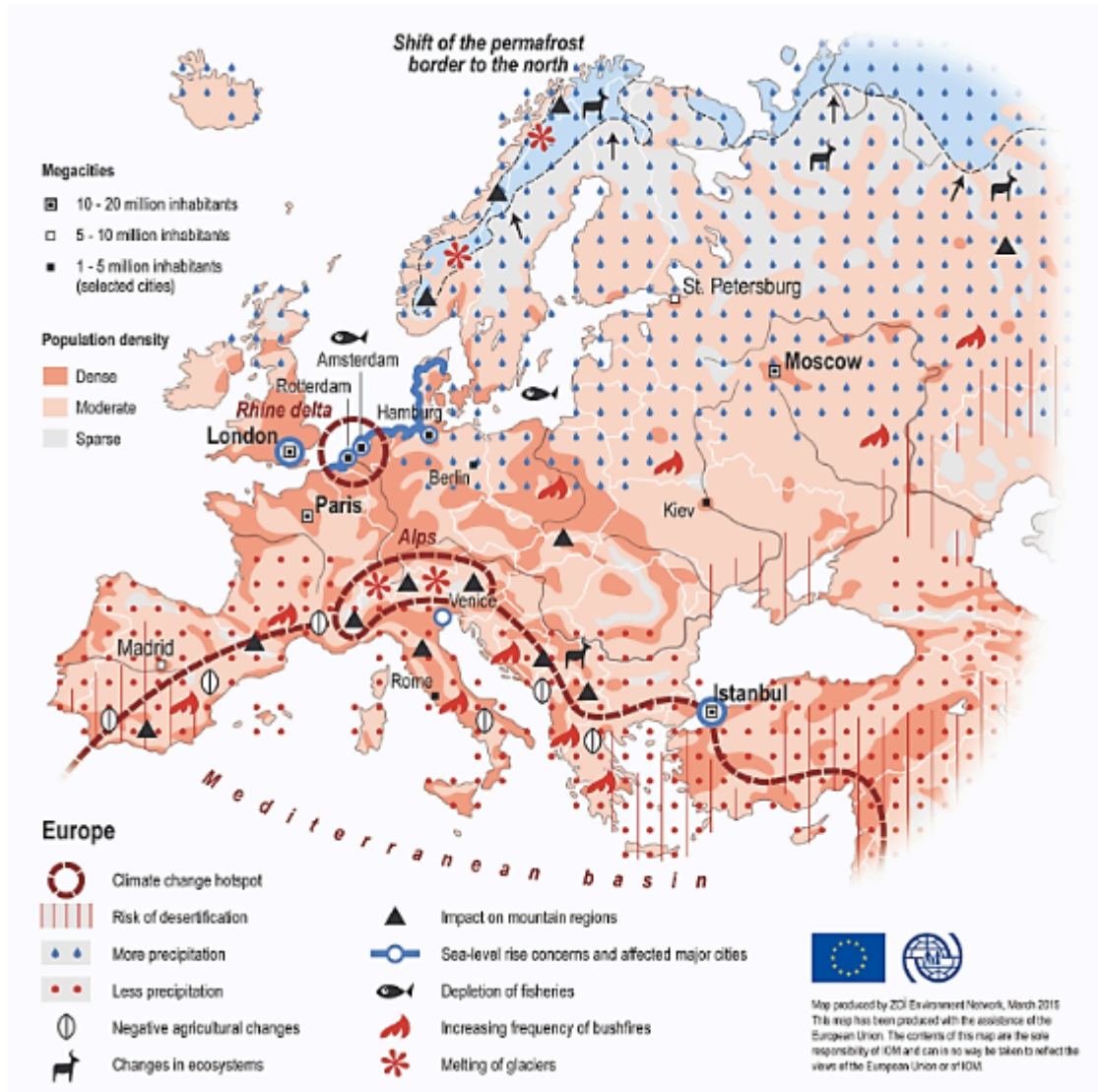
Antarctic ice sheet formed during the late Eocene 45-34 million years ago are estimated as [~800-2000 ppm](#) and up to 4 degrees Celsius above pre-industrial values, whereas the threshold of collapse is estimated as [600 ppm CO<sub>2</sub>](#) or even [lower](#). The [total mass loss](#) from the Antarctic ice sheet increased from  $40 \pm 9$  Gt/yr in 1979-1990 to  $50 \pm 14$  Gt/yr in 1989-2000,  $166 \pm 18$  Gt/yr in 1999-2009, and  $252 \pm 26$  Gt/yr in 2009-2017. Based on satellite gravity data the East Antarctic ice sheet is beginning to breakdown in places ([Jones 2019](#)), notably the Totten Glacier ([Rignot et al., 2019](#)), which may be [irreversible](#). According to [Mengel and Levermann \(2014\)](#) the Wilkes Basin in East Antarctica contains enough ice to raise global sea levels by 3-4 meters.



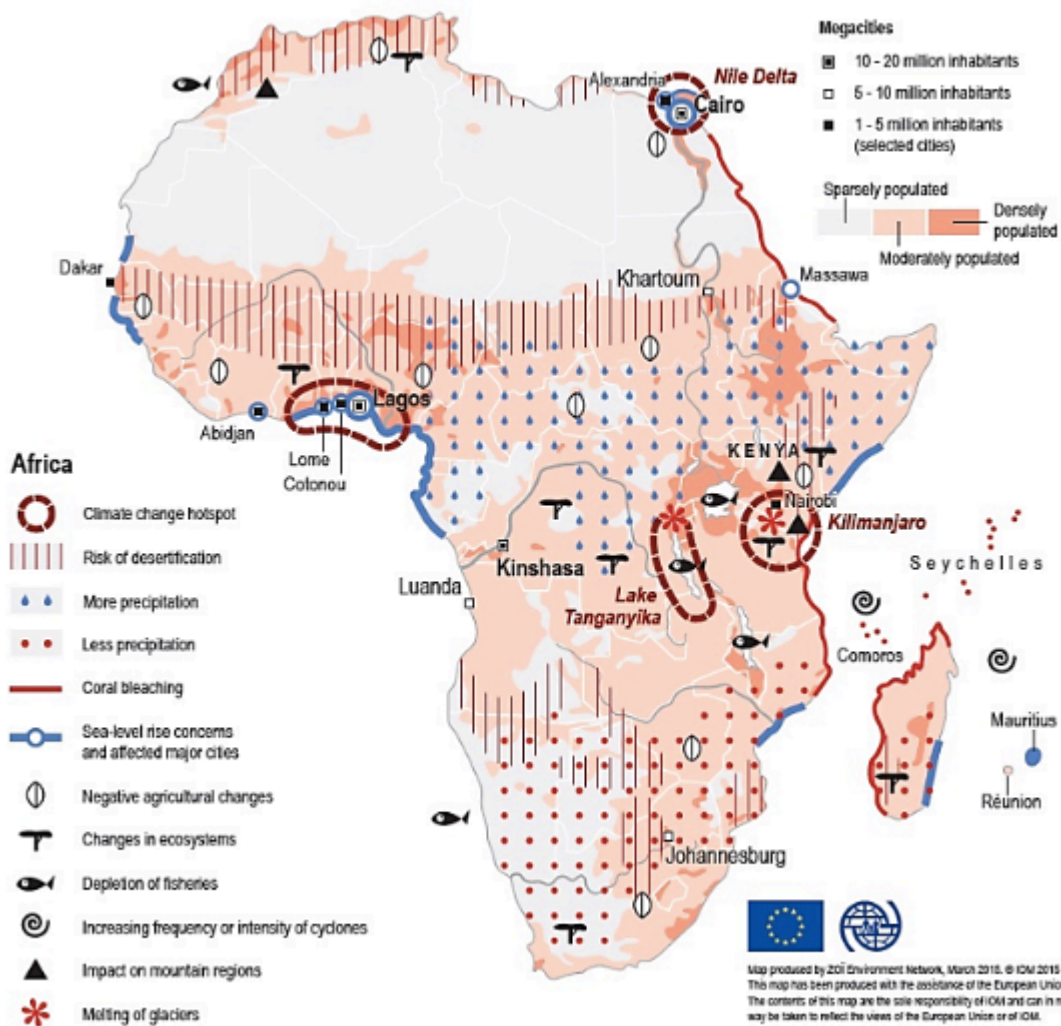
**Figure 4.** (A) New elevation showing the Greenland and Antarctic current [state of the ice sheets](#) accurate to a few meters in height, with elevation changes indicating melting at record pace, losing some 500 km<sup>3</sup> of ice per-year into the oceans; (B) Ice anomaly relative to the 2002-2016 mean for the [Greenland ice sheet](#) (magenta) and Antarctic ice sheet (cyan). Data are from GRACE; (C) the melting of sea ice [1978-2017](#), National Snow and Ice Data Centre (NSIDC)

### C. Migration of climate zones

The expansion of [warm tropical zones](#) and the polar-ward [migration of subtropical and temperate climate zones](#) are leading to a change in state in the global climate pattern. The migration of arid subtropical zones, such as the Sahara, Kalahari and central Australian deserts into temperate climate zones ensues in large scale [droughts](#), such in inland [Australia](#) and [southern Africa](#). In the northern hemisphere expansion of the Sahara desert northward, manifested by heat waves across the [Mediterranean and Europe](#) (Figure 5)



**Figure 5** (A) Migration of the subtropical Sahara climate zone (red spots) northward into the Mediterranean climate zone leads to warming, drying and fires over extensive parts of Spain, Portugal, southern France, Italy, Greece and Turkey, and to melting of glaciers in the Alps. Migration, Environment and Climate Change, International Organization for Migration Geneva - Switzerland (GMT +1); <https://environmentalmigration.iom.int/maps>



**Figure 5** (B) Southward encroachment of Kalahari Desert conditions (vertical lines and red spots) leading to warming and drying of parts of southern Africa. <https://environmentalmigration.iom.int/maps>

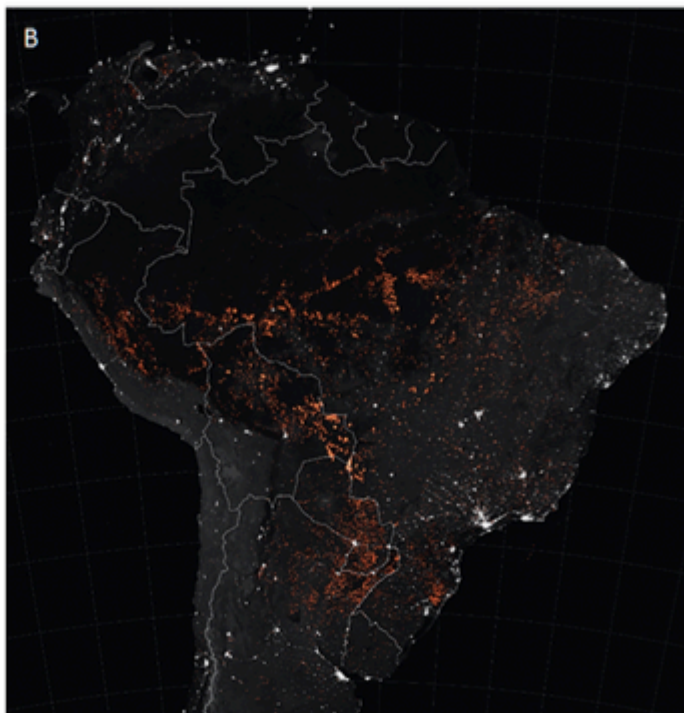
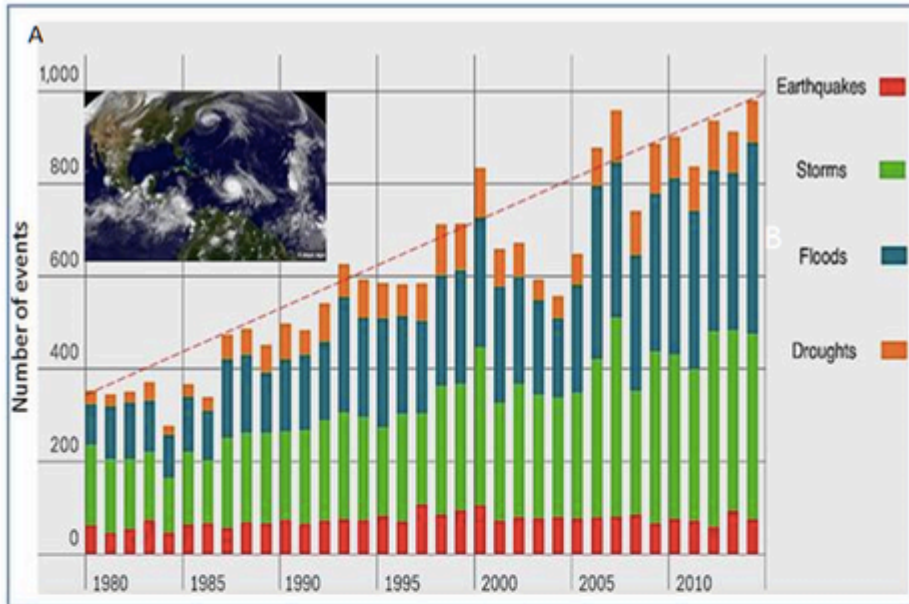
**D. Climate extremes**

Since the bulk of terrestrial vegetation has evolved under glacial-interglacial climate conditions, where GHG range between 180 - 300 ppm CO<sub>2</sub>, Global warming is turning large parts of Earth into a tinderbox, ignited by natural and human agents. By July and August 2019, as fires rage across large territories, including the Amazon forest, dubbed the *Planet's lungs* as it enriches the atmosphere in oxygen. When burnt the rainforest becomes of source of a large amount of CO<sub>2</sub>(Figure 6B), with some [72,843](#) fires in Brazil this year and extensive bushfires through [Siberia](#), Alaska, Greenland, southern Europe, parts of Australia and elsewhere, the planet's biosphere is progressively transformed. As [reported](#):

'Climate change is making dry seasons longer and forests more flammable. Increased temperatures are also resulting in more frequent tropical forest fires in non-drought years. And climate change may also be driving the increasing frequency and intensity of climate anomalies, such as El Niño events that affect fire season intensity across Amazonia.'

Extensive cyclones, floods, droughts, heat waves and fires (Figure 6B) increasingly ravage

large tracts of Earth. However, despite its foundation in the basic laws of physics (the [black body radiation](#) laws of Planck, Kirchoff' and Stefan Boltzmann), as well as empirical observations around the world by major climate research bodies (NOAA, NASA, NSIDC, IPCC, World Meteorological Organization, Hadley-Met, Tindale, Potsdam, BOM, CSIRO and others), the anthropogenic origin, scale and pace of climate change remain subject to extensively propagated [denial and untruths](#).



**Figure 6.**(A) Extreme weather events around the world 1980-2018, including earthquakes, storms, floods, droughts. [Munich Re-insurance](#). (B) A satellite infrared image of [South America fires](#) (red dots) during July and August, 2019, NASA.

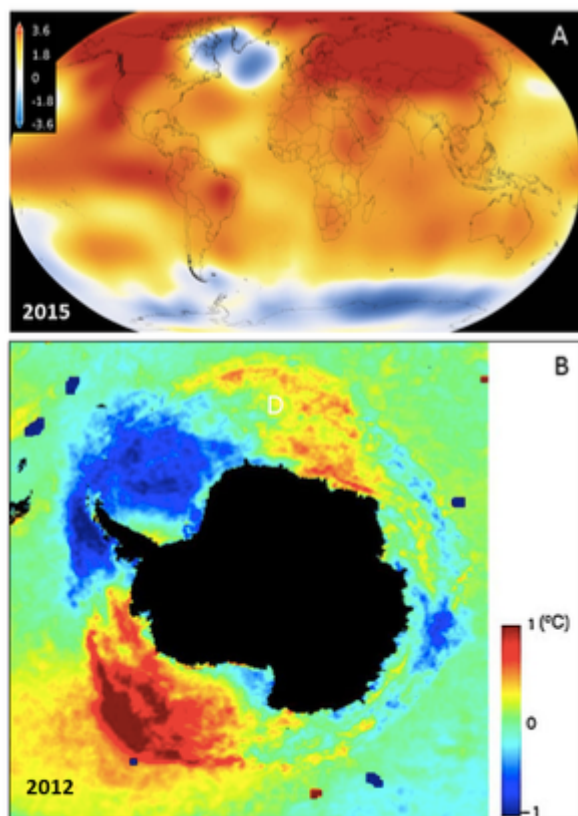
### E. An uncharted climate territory

Whereas strict analogies between Quaternary and Anthropocene climate developments is not possible, elements of the glacial-interglacial history are relevant for an understanding of



current and future climate events. The rise of total greenhouse gas (GHG), expressed as CO<sub>2</sub>-equivalents, to 496 ppm CO<sub>2</sub>-e (Figure 1), within less than a century represents an extreme atmospheric event. It raised GHG concentrations from Holocene levels to the range of the Miocene (34–23 Ma) when CO<sub>2</sub> level was between [300 and 530 ppm](#). As the glacial sheets disintegrate, cold ice-melt water flowing into the ocean ensue in large cold water [pools](#), a pattern recorded following peak interglacial phases over the [last 450,000 years](#), currently manifested by the growth of cold regions in north Atlantic Ocean [south of Greenland](#) and in the Southern Ocean fringing Antarctica (Figure 7).

Warming of +3°C to +4°C above pre-industrial levels, leading to enhanced ice-sheet melt, would raise sea levels by at least [2 to 5 meters](#) toward the end of the century and, delayed by [hysteresis](#), likely by 25 meters in the longer term. [Golledge et al.](#) (2019) show meltwater from Greenland will lead to substantial slowing of the Atlantic overturning circulation, while meltwater from Antarctica will trap warm water [below the sea surface](#), increasing Antarctic ice loss. Whereas the effect of low-density ice melt water on the surrounding oceans is generally not included in many models, depending on [amplifying feedbacks](#), prolonged Greenland and Antarctic melting and consequent cooling of surrounding ocean sectors as well as penetration of freezing air masses through [weakened polar boundaries](#) may have profound effect on future climate change trajectories (Figure 8).



**Figure 7(A)** Global warming map ([NASA 2018](#)). Note the cool ocean regions south of Greenland and along the Antarctic. Credits: Scientific Visualization Studio/Goddard Space Flight Center; **(B)** 2012 Ocean temperatures around Antarctica ([NASA 2012](#)).

Climate projections for 2100–2300 by the IPCC [AR5 Synthesis Report, 2014](#) portray predominantly [linear to curved models](#) of greenhouse gas, global temperatures and sea level changes. These models however appear to take limited account of [amplifying feedbacks](#) from land and ocean and of the effects of cold ice-melt on the oceans. According

to [Steffen et al. \(2018\)](#)

“self-reinforcing feedbacks could push the Earth System toward a planetary threshold” and “would lead to a much higher global average temperature than any interglacial in the past 1.2 million years and to sea levels significantly higher than at any time in the Holocene”.

Amplifying feedbacks of global warming include:

A. The [albedo-flip](#) of melting sea ice and ice sheets and the increase of the water surface area and thereby sequestration of CO<sub>2</sub>. [Hudson \(2011\)](#) estimates a rise in radiative forcing due to removal of Arctic summer sea ice as 0.7 Watt/m<sup>2</sup>, a value close to the total of methane release since 1750.

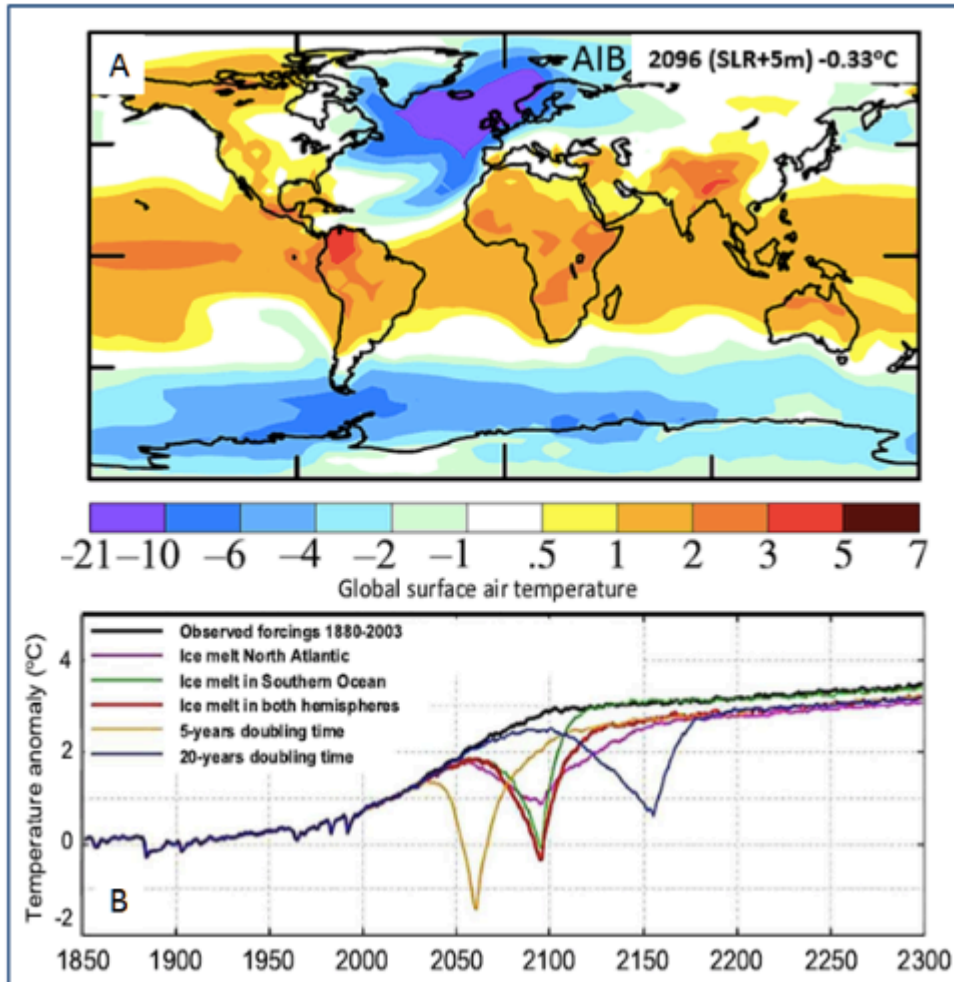
B. Reduced [ocean CO<sub>2</sub> intake](#) due to lesser solubility of the gas with higher temperatures.

C. Vegetation desiccation and burning in some regions, and thereby released CO<sub>2</sub> and reduced evaporation and its cooling effect. This factor and the increase of precipitation in other regions lead to differential feedbacks from vegetation as the globe warms ([Notaro et al. 2007](#)).

D. An increase in [wildfires](#), releasing greenhouse gases (Figure 6).

E. Release of [methane](#) from permafrost, bogs and sediments and other factors.

Linear temperature models appear to take limited account of the effects on the [oceans](#) of ice melt water derived from the large ice sheets, including the possibility of a significant [stadial event](#) such as already started in oceanic tracts fringing Greenland and Antarctica (Figure 7) and modelled by [Hansen et al. \(2016\)](#). In the shorter to medium term sea level rises would ensue from the Greenland ice sheet (6-7 meter sea level rise) and West Antarctic ice sheet melt (4.8 meter sea level rise). Referring to major past stadial events, including the 8200 years-old [Laurentian melt](#) and the [12.7-11.9 younger dry as](#) event, a protracted breakdown of parts of the Antarctic ice sheet could result in major sea level rise and extensive cooling of southern latitudes and beyond, parallel with warming of tropical and mid-latitudes (Figure 8) ([Hansen et al. 2016](#)). The temperature contrast between polar-derived cold fronts and tropical air masses is bound to lead to extreme weather events, echoed among other in *Storms of my grandchildren* ([Hansen, 2010](#)).



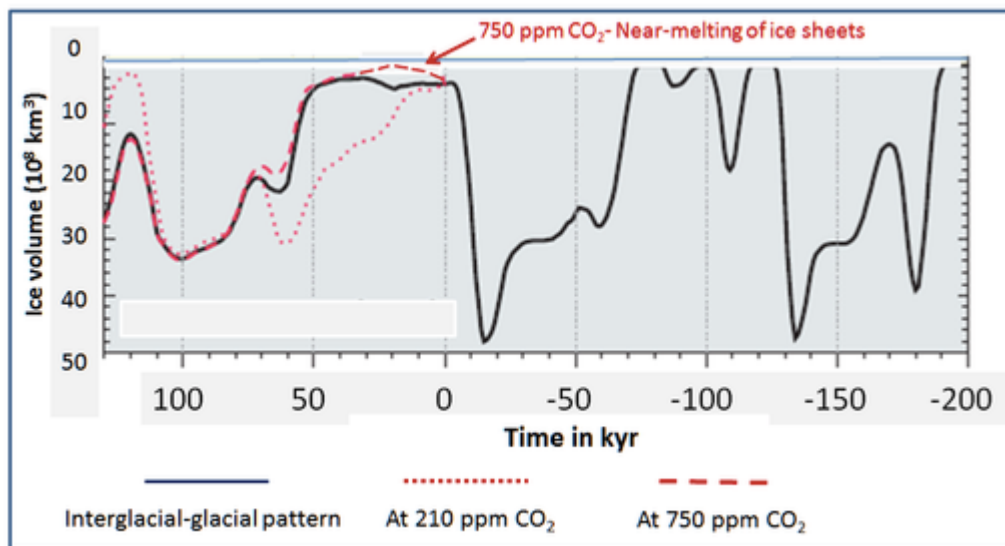
**Figure 8.** (A) Model Surface-air temperature ( $^{\circ}\text{C}$ ) for 2096 relative to 1880–1920 (Hansen et al 2016). The projection betrays major cooling of the North Atlantic Ocean, cooling of the circum-Antarctic Ocean and further warming in the tropics, subtropics and the interior of continents; (B) Modeled surface-air temperatures ( $^{\circ}\text{C}$ ) to 2300 AD relative to 1880–1920 for several ice melt rate scenarios, displaying a stadial cooling event at a time dependent on the ice melt doubling time (Hansen et al., 2016). Courtesy Prof James Hansen.

Within and beyond 2100–2300 projections (Figure 8A, B) lies an **uncharted climate territory**, where continuing melting of the Antarctic ice sheet, further cooling of neighboring sectors of the oceans and climate contrasts with GHG-induced warming of land areas (Figure 8A), ensue in chaotic climate disruptions (Figure 8B). Given the thousands to tens of thousands years longevity of atmospheric greenhouse gases (Solomon et al., 2009; Eby et al 2009), the onset of the next ice age is likely to be delayed on the scale of tens of thousands of years (Berger and Loutre, 2002) through an exceptionally long interglacial period (Figure 9).

These authors state:

‘The present day  $\text{CO}_2$  concentration (now  $>410$  ppm) is already well above typical interglacial values of  $\sim 290$  ppmv. This study models increases to up to 750 ppmv over the next 200 years, returning to natural levels by 1000 years. The results suggest that, under very small insolation variations, there is a threshold value of value of  $\text{CO}_2$  above which the Greenland Ice Sheet disappears. The climate system may take 50,000 years to assimilate the

impacts of human activities during the early third millennium. In this case, an “**irreversible greenhouse effect**” could become the most likely future climate. If the Greenland and west Antarctic Ice Sheets disappear completely, then today’s “Anthropocene” may only be a transition between the Quaternary and the next geological period.’



**Figure 9.** Simulated Northern Hemisphere ice volume (increasing downward) for the period 200,000 years BP to 130,000 years in the future, modified after a part of [Berger and Loutre 2002](#). Time is negative in the past and positive in the future. For the future, three  $\text{CO}_2$  scenarios were used: last glacial-interglacial values (solid line), a human-induced concentration of 750 ppm (dashed line), and a constant concentration of 210 ppm inducing a return to a glacial state (dotted line).

As conveyed by leading scientists “Climate change is now reaching the **end-game**, where very soon humanity must choose between taking unprecedented action or accepting that it has been left too late and bear the consequences” ([Prof. Hans Joachim Schellnhuber](#))... “We’ve reached a point where we have a crisis, an emergency, but people don’t know that ... There’s a big gap between what’s understood about global warming by the scientific community and what is known by the public and policymakers” ([James Hansen](#)).

Climate scientists find themselves in a quandary similar to medical doctors, committed to help the ill yet need to communicate grave diagnoses. How do scientists tell people the current spate of [extreme weather events](#), including cyclones, devastating islands from the Caribbean to the Philippine, [floods](#) devastating coastal regions and river valleys from Mozambique to Kerala, Pakistan and Townsville, and fires burning extensive tracts of the living world can only intensify in a rapidly warming world? How do scientists tell the people that their children are growing into a world where survival under a mean temperatures higher than +2 degrees Celsius (above pre-industrial temperatures) is likely to be painful and, in some parts of the world, impossible, let alone under +4 degrees Celsius [projected by the IPCC](#)?

## F. Summary and conclusions

1. The current growth rate of atmospheric greenhouse gas is the fastest recorded for the last [55 million years](#).

2. By the mid-21<sup>st</sup> century, at the current CO<sub>2</sub> rise rates of 2 to 3 ppm/year, a CO<sub>2</sub> level of >750 ppm is likely to transcend the climate tipping points indicated by [Lenton et al. 2008](#) and [Schellnhuber 2009](#).
3. The current extreme rise rates of GHG ([2.86 ppm CO<sub>2</sub>/year](#)) and temperature ([0.15-0.20°C per decade](#) since 1975) raise doubt with regard to linear future climate projections.
4. Global greenhouse gases have reached a level exceeding the stability threshold of the Greenland and Antarctic ice sheets, which are melting at an [accelerated rate](#).
5. Allowing for the transient albedo-enhancing effects of sulphur dioxide and other aerosols, mean global temperature has reached approximately 2.0 degrees Celsius above pre-industrial temperatures.
6. Due to [hysteresis](#) the large ice sheets would outlast their melting temperatures.
7. Land areas would be markedly reduced due to a rise to Miocene-like sea levels of approximately [40±15 meters](#) above pre-industrial levels.
8. Cold ice melt water flowing from the ice sheets into the oceans at an [accelerated rate](#) is reducing temperatures in large tracts in the North Atlantic and circum-Antarctic.
9. Strong [temperature contrasts](#) between cold polar-derived and warm tropical air and water masses are likely to result in extreme weather events, retarding habitats and agriculture over coastal regions and other parts of the world.
10. In the wake of partial melting of the large ice sheets, the Earth climate zones would continue to shift polar-ward, expanding tropical to super-tropical regions such as existed in the Miocene ([5.3-23 million years ago](#)) and reducing temperate climate zones and polar ice sheets.
11. Current greenhouse gas forcing and global mean temperature are approaching Miocene Optimum-like composition, bar the hysteresis effects of reduced ice sheets (Figure 4A).
12. The effect of high atmospheric greenhouse gas levels would be for the next ice age to be delayed on a scale of [tens of thousands of years](#), during which chaotic tropical to hyperthermal conditions would persist until solar radiation and atmospheric CO<sub>2</sub> subsided below ~300 ppm.
13. Humans will survive in relatively favorable parts of Earth, such as sub-polar regions and sheltered mountain valleys, where gathering of flora and hunting of remaining fauna may be possible.

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## Notes

[1] The index uses 1990 as a baseline year with a value of 1. The index increased every year since 1979. <https://www.co2.earth/annual-ghg-index-aggi>

[2] where a physical property lags behind changes in the effect causing it

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