Climate Change: The Fatal Road to 4 Degrees Celsius

Extreme GHG and T°C rise rates exceed climate tipping thresholds

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Theme: Environment
In-depth Report: Climate Change

Global CO_2 rise and warming rates have reached a large factor to an order of magnitude higher than those of the past geological and mass extinction events, with major implications for the shift in climate zones and the nature and speed of current extreme weather events. Given the abrupt change in state of the atmosphere-ocean-cryosphere-land system, accelerating since the mid-20th century, the terms climate change and global warming no longer reflect the nature of the climate extremes consequent on this shift. Further to NASA's reported mean land-ocean temperature rise to +1.18°C for March 2020, relative to the 1951-1980 baseline, large parts of the continents, including Siberia, central Asia, Canada, parts of west Africa, eastern South America and Australia are warming toward mean temperatures of +2°C and higher.

The rate exceeds that of the Last Glacial Termination (LGT) (21–8 kyr), the Paleocene-Eocene hyperthermal event (PETM) (55.9 Ma) and the Cretaceous-Tertiary boundary (K-T) (64.98 Ma) impact event. A principal question arises regarding the relationships between the warming rate and the nature and progression of the current migration climate zones toward the poles, including changes in the atmosphere and ocean current systems. Significant transient cooling pauses, or stadials, are projected as a consequence of the flow of cold ice melt water from Greenland and Antarctica into the oceans.

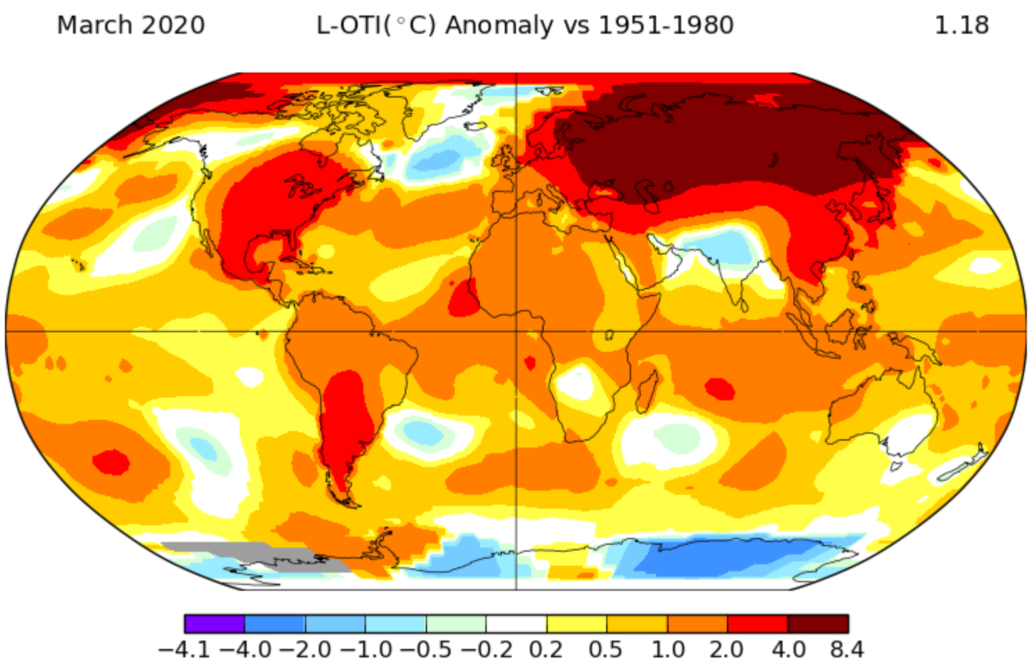

Figure 1. Global temperature distribution in March 2020, relative to a 1951-1980 baseline. NASA GISS.

Table 1. Paleoclimate estimates of mean land and sea temperatures, mean CO_2 concentrations (ppm) and mean T°C rise rates per year.

Age	Interval (warming period)	Mean land and sea temp change °C	Warming rate (°C/yr)	CO_2 change (ppm)	CO_2 change rate (ppm/ year)	Reference
K-T impact 64.98 Ma	10,000 years from the impact	Short freeze followed by ~+7.5°C	~0.00075	~500 to 2300 ppm	0.18 ppm/yr	Beerling et al. 2002
PETM 55.9 Ma	~6000 to 7000 years	~ +5 to 9°C	~0.0008 - 0.0015	~ 1000 to 1700 ppm; Added 700 ppm	~0.1 to 0.11 ppm/yr	Zeebe et al. 2009
PETM	20,000 years	5 to 9°C	0.00025 - 0.0004	Added 1200 ppm	0.06 to 0.075 ppm/yr	McInerney and Wing 2011
The Last Glacial Termination; 17.5–10 kyr	7500 years	-3.5°C	0.00046	186 to 265 ppm	0.010 ppm/year	Shakun et al. 2002
1750-2020	270 years	~2°C Without aerosol albedo effects	~0.0074	300 to 412 ppm	~0.415 ppm/year	NASA/NOAA
	Anthropocene/LGT		**Anthropocene/PETM**		**Anthropocene/KT**	
CO_2	$CO_{2\,ANTH/LGT}$ = x41		$CO_{2\,ANTH/PETM}$ = x3.8 - 6.9		$CO_{2\,ANTH/KT}$ = x2.3	
TEMP	$T°C_{ANTH/LGT}$ = x16		$T°C_{ANTH/PETM}$ = x4.9 - 9.25		$T°C_{ANTH/KT}$ = x9.9	

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The K-T impact and subsequent warming

According to Beerling et al. (2002) the CO_2 change triggered by the K-T impact event 65 Ma years ago involved a rise from about 400-500 ppm to 2300 ppm over 10.000 years from the impact (Fig. 2) at a rate of 0.18 ppm/year. This is less than the mean Anthropocene CO_2 rise rate of 0.415 ppm/year and an order of magnitude less than the 2 to 3 ppm/year rise rate in the 21st century. Likewise the Anthropocene temperature rise rate of ~ 0.0074°C/year is high by an order of magnitude as compared to the K-T impact event rate of~ 0.00075°C/year (Table 1) reported by Beerling et al. (2002).

Beerling et al.'s (2002) estimate, based on fossil fern proxies, implies an initial injection of at least 6,400 $GtCO_2$ and possibly as high as 13,000 $GtCO_2$ into the atmosphere, significantly higher than values derived by Pope et al. (1997). This would increase climate forcing by +12 Wm^{-2} and mean warming of ~7.5°C, which would have strongly stressed ecosystems already affected by cold temperatures and the blockage of sunlight during the impact winter and associated mass extinction at the KT boundary (O'Keefe et al. 1989).

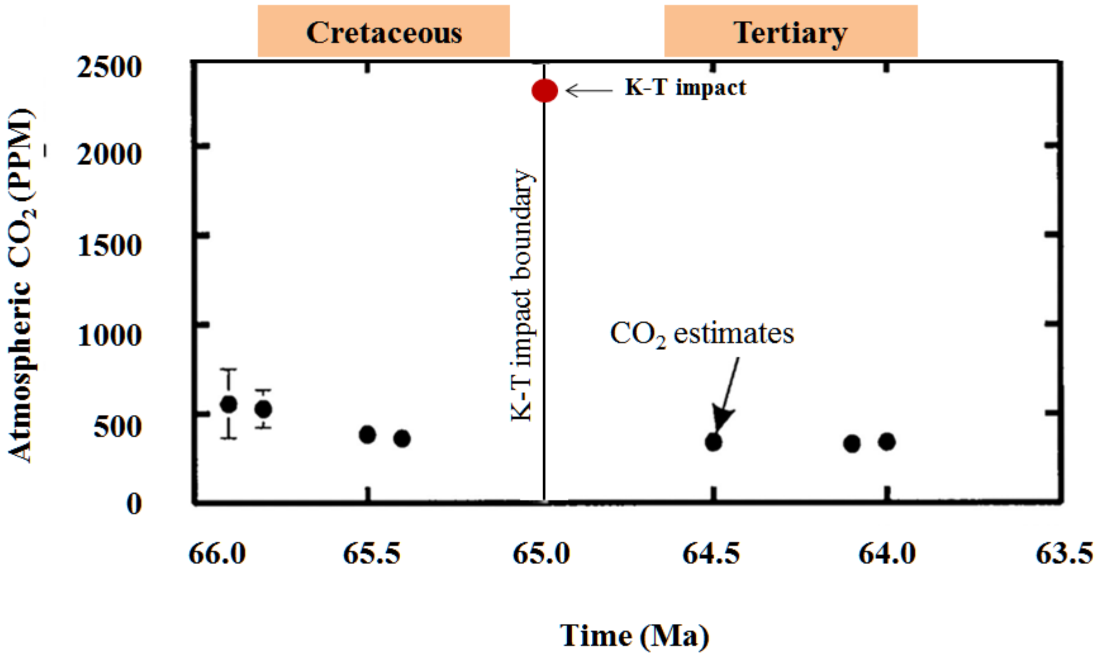

Figure 2. Reconstructed atmospheric CO_2 variations during the Late Cretaceous–Early Tertiary derived from the SI (Stomata index) of fossil leaf cuticles calibrated by using inverse regression and stomatal ratios. Beerling et al. (2002).

The PETM hyperthermal event

The Palaeocene–Eocene Thermal Maximum, about 55.9 Ma, triggered the release of a large mass of light ^{13}C-depleted carbon suggestive of an organic source, likely methane, has led to a global surface temperature rise of 5 – 9°C within a few thousand years (Table 1; Fig. 3). Deep-sea carbonate dissolution indices and stable carbon isotope composition were used to estimate the initial carbon pulse to a magnitude of 3,000 PgC or less. As a result, atmospheric carbon dioxide concentrations increased during the main event by up to 70% compared with pre-event levels, leading to a global surface temperatures rose by 5–9°C within a few thousand years.

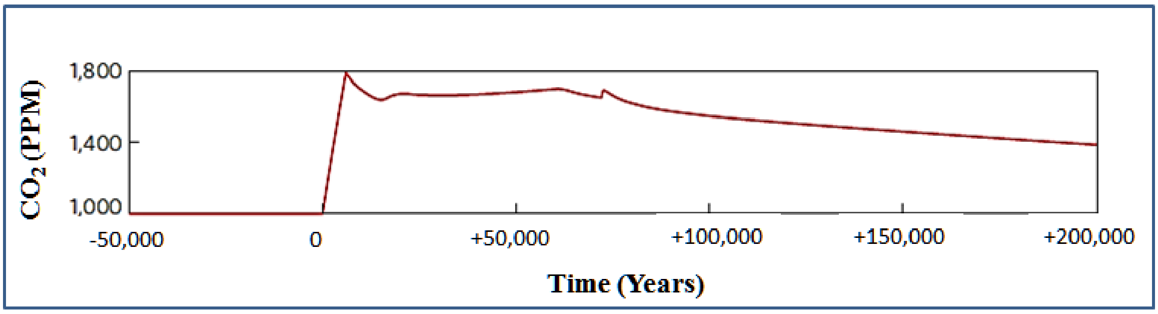

Figure 3. Simulated atmospheric CO2 at and after the Palaeocene-Eocene boundary (after Zeebe et al. (2009).

The last glacial termination

Paleoclimate indices based on ice cores and isotopic evidence suggest temperature rise generally correlates with CO_2 during the Last Glacial Termination between 17.5 kyr to 10 kyr. Whereas the rise rates of CO_2 and temperature are broadly parallel the temperature somewhat lags behind CO_2 (Figure 2), including changes of CO_2 (186 – 265 ppm) and of temperature (T°C -3.3°C – +0.2°C) (Fig. 4). A rise rate of ~0.010 ppm CO_2/year and of temperature ~0.00046°C/year are indicated (Table 1) (Shakun et al., 2012). Differences between temperature changes of the Northern Hemisphere and Southern Hemisphere correspond to variations in the strength of the Atlantic meridional overturning circulation.

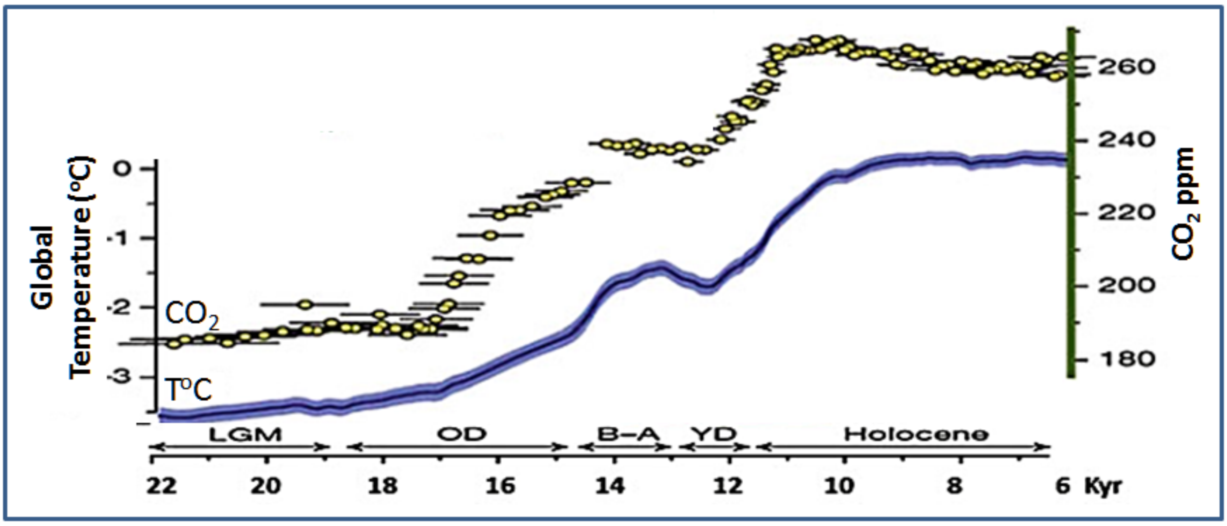

Figure 4. Global CO_2 and temperature during the last glacial termination (After Shakun et al. 2012).(LGM – Last Glacial Maximum; OD – Older Dryas; B-A – Bølling–Allerød; YD Younger Dryas).

Trajectories and rates of global CO_2 rise and warming

The rates at which atmospheric composition and climate changes occur constitute major control over the survival versus extinction of species. Based on paleo-proxy estimates of greenhouse gas levels and of mean temperatures, using oxygen and carbon isotopes, fossil plants, fossil organic matter, trace elements, the rate of CO_2 rise since ~1750 (Anthropocene) ($CO_{2\ ANTH}$) exceeds that of the last glacial termination ($CO_{2\ LGT}$) by an order of magnitude ($CO_{2\ ANTH}/CO_{2\ LGT}$ = 41) and that of the Paleocene-Eocene Thermal Maximum ($CO_{2\ PETM}$) by a high factor ($CO_{2\ ANTH}/CO_{2\ PETM}$ ~ 3.8–6.9)(Table 1). The rise rate of mean global temperature exceeds that of the LGT and the PETM by a large factor to an order of magnitude (Table 1; Figs 5 and 6). It can be expected that such extreme rates of change will be manifest in real time by observed shifts in state of global and regional climates and the intensity and frequency of extreme weather events, including the following observations:

- A shift in climate zones (Fig. 7) including expansion of the tropics and migration of moderate Mediterranean-type climate zones toward the poles, estimated at a rate of 56-111 km per decade (Thurton 2017), signifying a fundamental shift in state of the Earth's climate regime.
- A high rate of ice melt and development of cool ocean pools south of Greenland and around Antarctica (Fig. 8a) developing into cool ocean regions and stadial climate conditions (Fig. 8b).
- Reduced temperature differences between the polar zones and mid-latitudes and thereby weakening of the polar boundaries and the polar jet stream boundary.
- Weakening of the North Atlantic Thermal Circulation.
- Changes in the southern ocean Antarctic oscillation and the Antarctic vortex.
- The rapid increase in extreme weather events, including droughts, heat waves, fires, cyclones and storms.

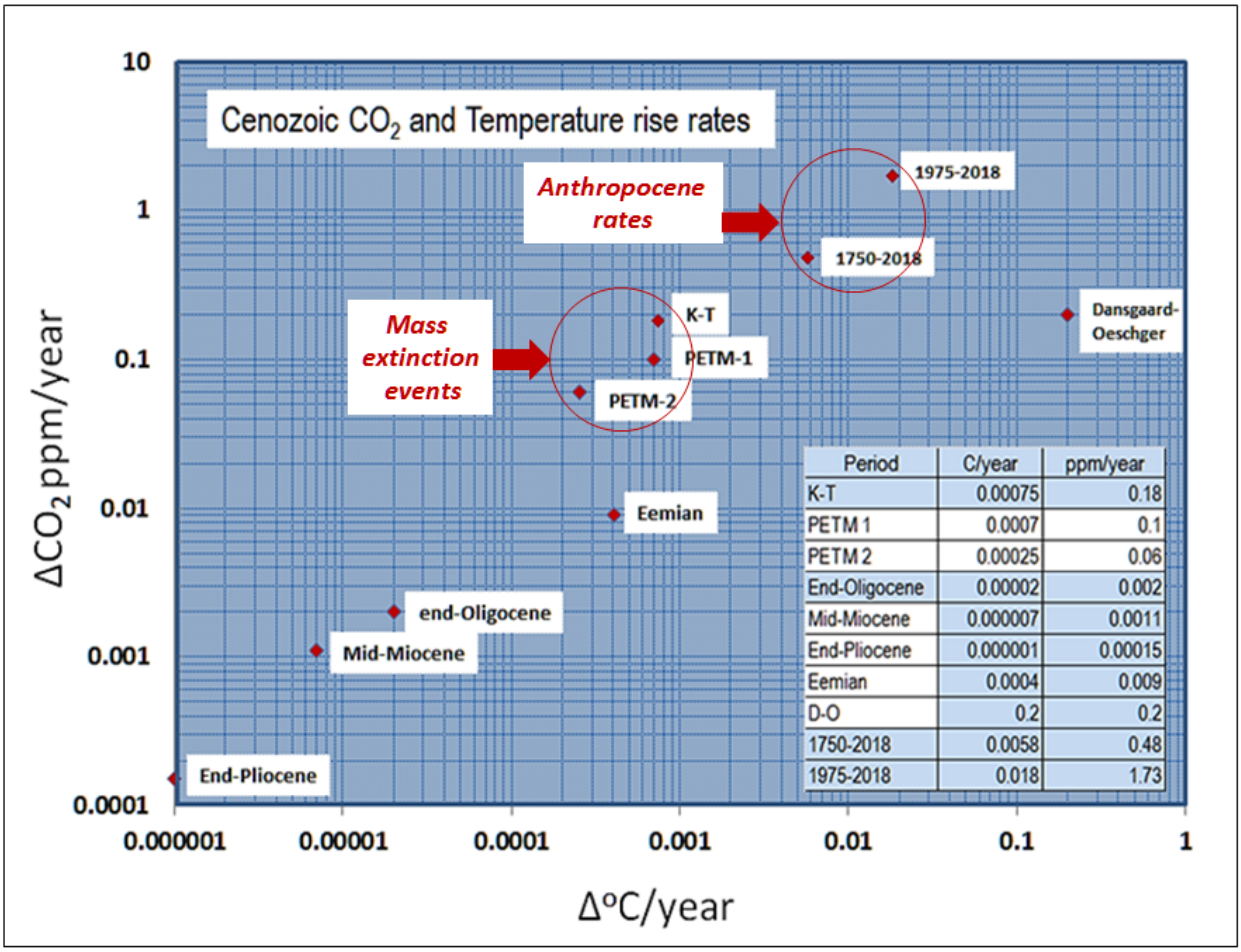

Figure 5. Cenozoic and Anthropocene CO_2 and temperature rise rates.

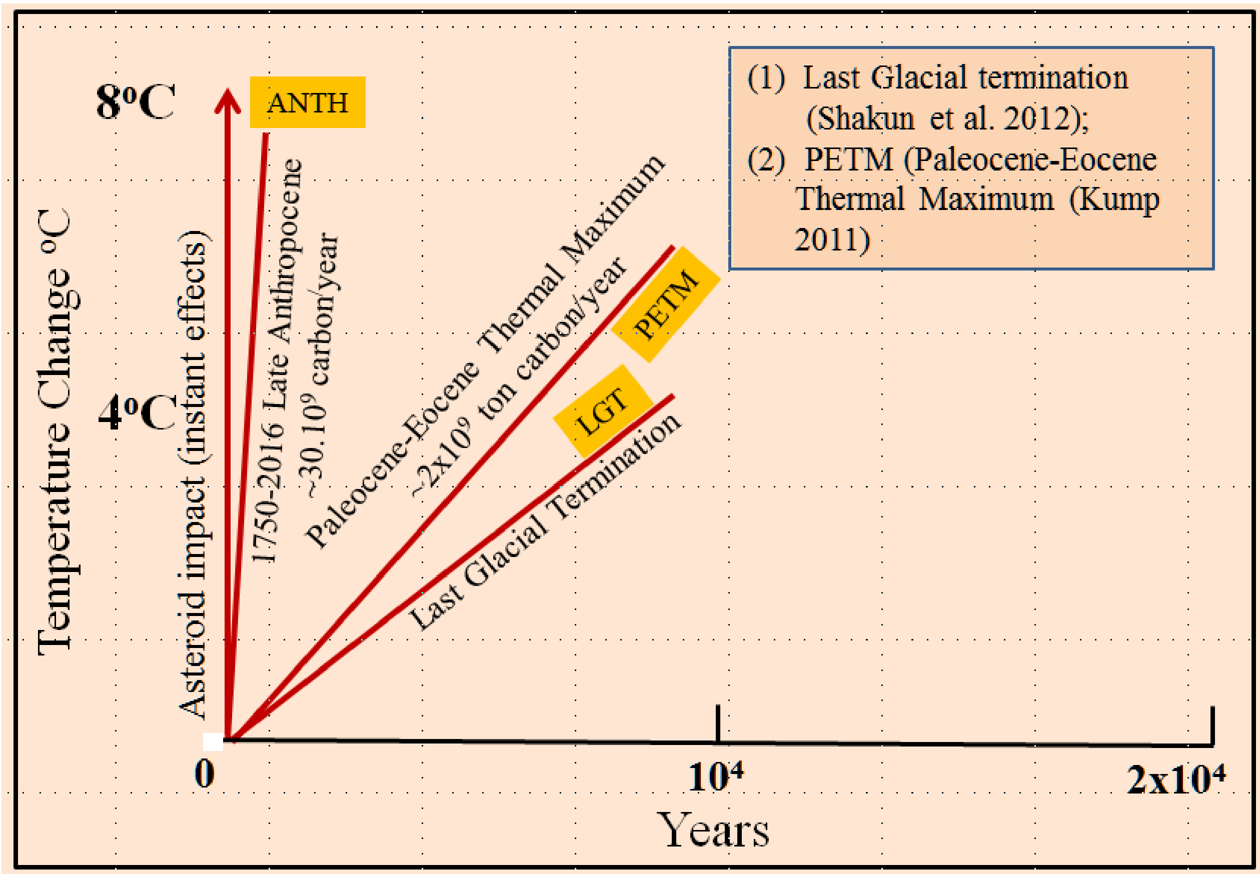

Figure 6. A comparison between rates of mean global temperature rise during:

(1) the last Glacial Termination (after Shakun et al. 2012);

(2) the PETM (Paleocene-Eocene Thermal Maximum, after Kump 2011);

(3) the late Anthropocene (1750–2019), and

(4) an asteroid impact. In the latter instance, temperature associated with CO_2 rise would lag by some weeks or months behind aerosol-induced cooling.

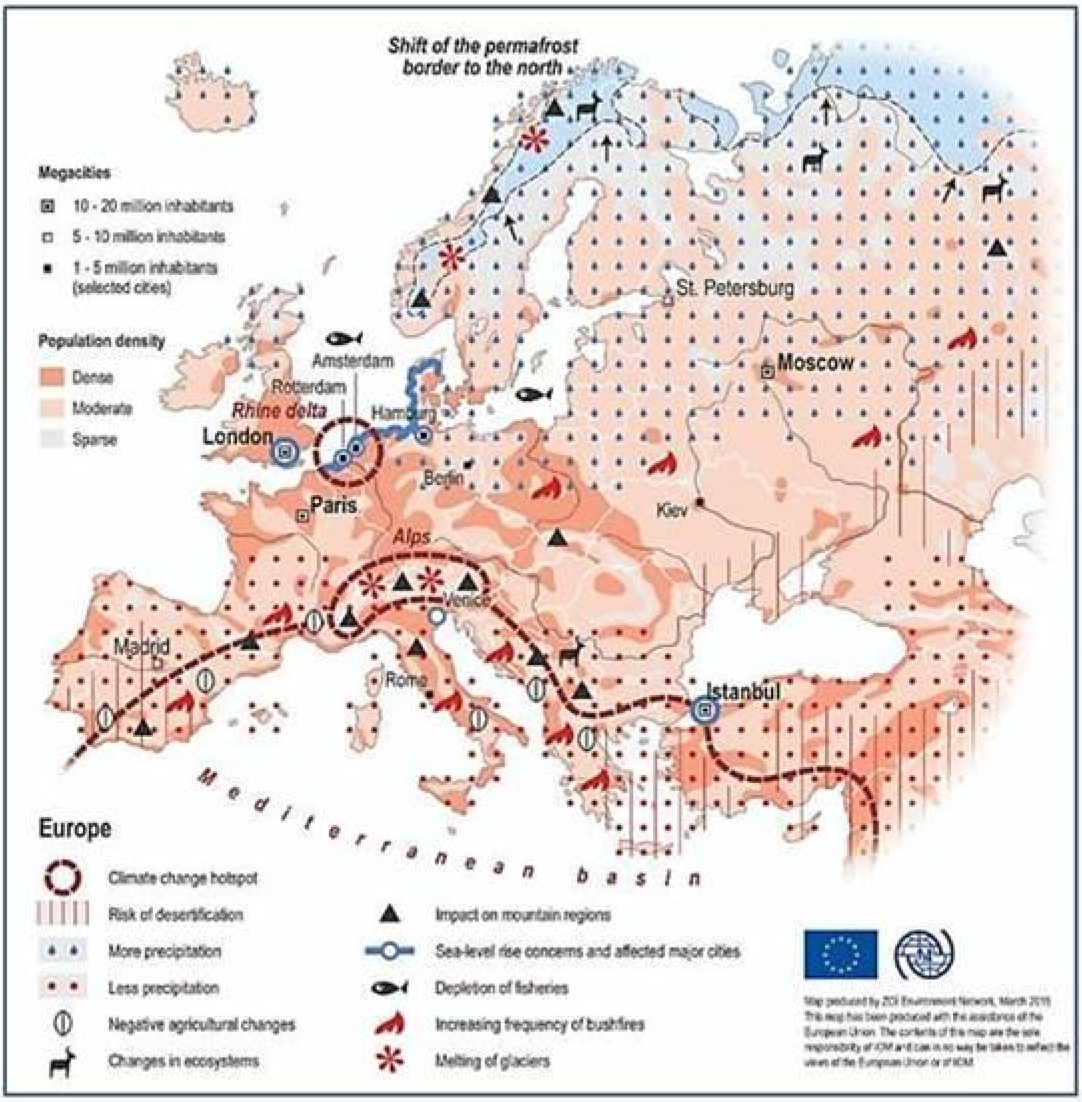

Figure 7. Migration of the subtropical Sahara climate zone (red spots) northward into the Mediterranean climate zone leads to warming, drying and fires over extensive parts of Spain, Portugal, southern France, Italy, Greece and Turkey, and to melting of glaciers in the Alps. Migration, Environment and Climate Change, International Organization for Migration, Geneva, Switzerland. With permission of the IOM UN Migration. The regional impacts of climate change map extracted from The Atlas of Environmental Migration (Ionesco D., Mokhnacheva D. and Gemenne F., Routledge, Abingdon, 2017), p. 63 © IOM (Mokhnacheva, Ionesco), Gemenne, Zoï Environment Network, 2015. Sources: IPCC (2013, 2014)

By contrast to linear IPCC climate projections for 2100-2300, climate modelling for the 21st century by Hansen et al. 2016 suggests major effects of ice melt water flow into the oceans from the ice sheets, leading to stadial cooling of parts of the oceans, changing the global temperature pattern from that of the early 21st century (Figs 8, 9a) to the late 21st century

(Fig. 9b).

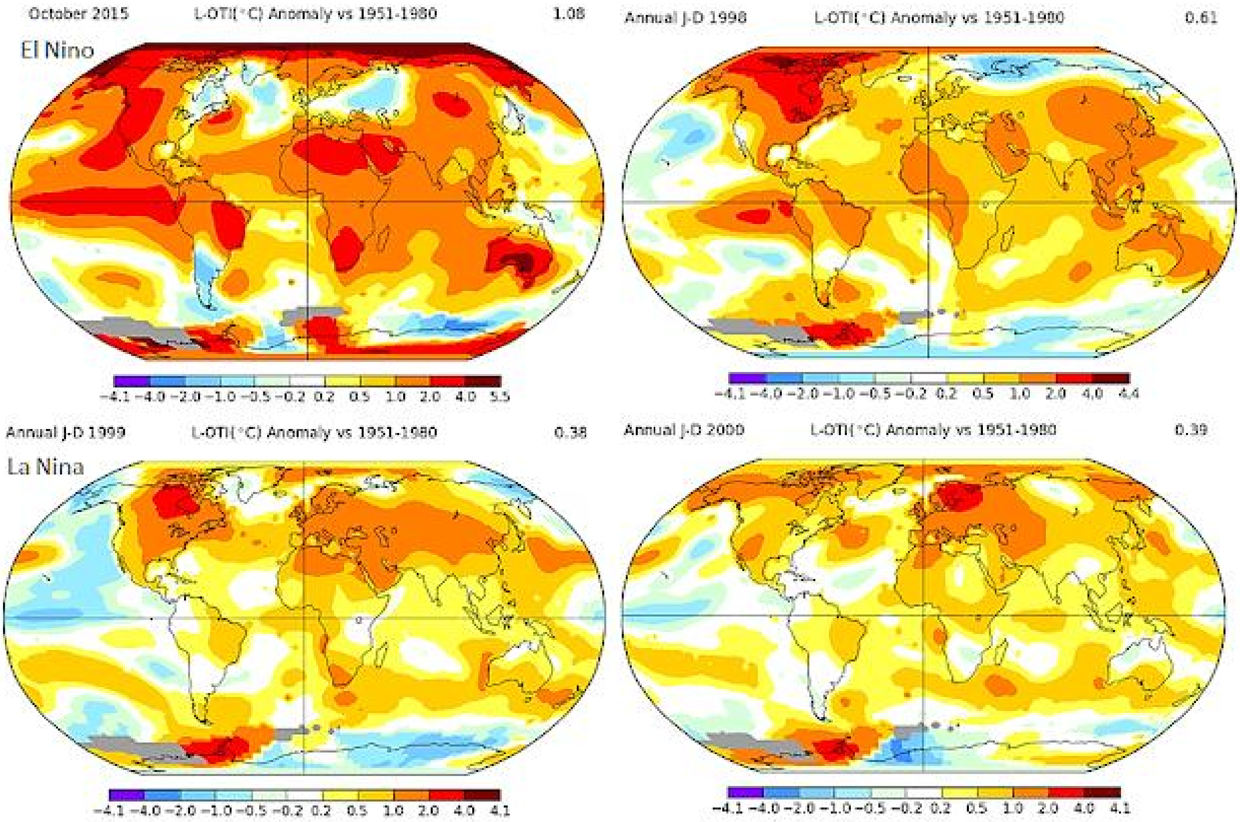

Figure 8. Global temperature patterns during El Nino and La Nina events. NASA GISS

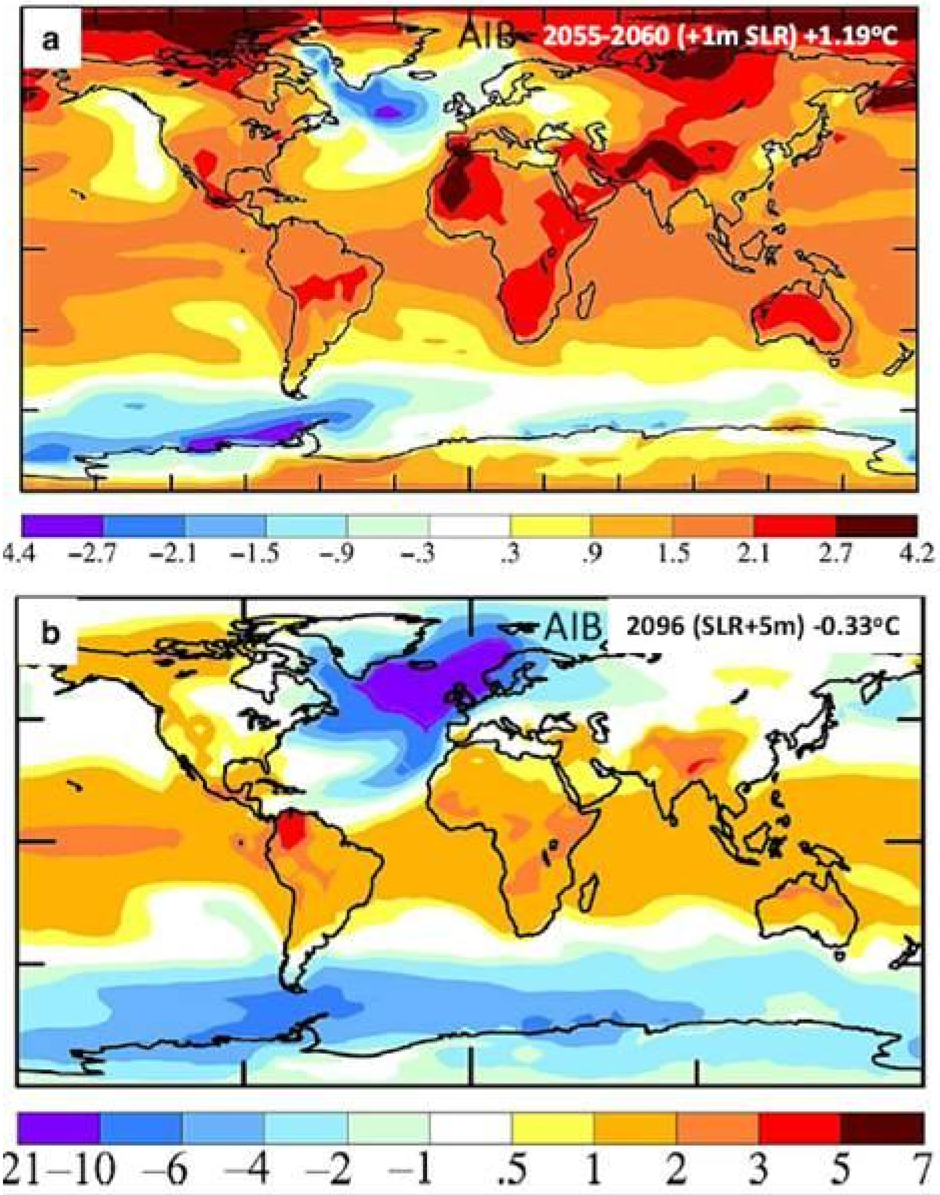

Figure 9. (a) An [A1B](#) model of surface-air temperature change for 2055-2060 relative to 1880-1920 (+1 meters sea level rise) for modified forcing ([Hansen et al. 2016](#));
(b) A1B model surface-air temperatures in 2096 relative to 1880-1920 (+5 meters sea level rise) for 10 years ice melt doubling time in the southern hemisphere and partial global cooling of -0.33°C (Hansen et al. 2016).

Summary and conclusions

1. Late 20th century to early 21asrt century global greenhouse gas levels and regional warming rates have reached a high factor to an order of magnitude faster than those of past geological and mass extinction events, with major implications for the nature and speed of extreme weather events.
2. The Anthropocene CO_2 rise and warming rates exceed that of the Last Glacial Termination (LGT) (21–8kyr), the Paleocene-Eocene hyperthermal event (PETM) (55.9 Ma) and the post-impact Cretaceous-Tertiary boundary (K-T) (64.98 Ma).
3. Further to NASA’s reported mean land-ocean temperature rise of +[1.18°C](#) in March 2020, relative to the 1951-1980 baseline, large parts of the continents, including central Asia, west Africa eastern South America and Australia are warming toward mean temperatures of +2°C and higher.
4. Major consequences of the current shift in state of the climate system pertain to

the weakening of the polar boundaries and the migration of climate zones toward the poles. Transient cooling pauses are projected as a result of the flow of cold ice melt water from Greenland and Antarctica into the oceans, leading to stadial cooling intervals.

5. Given the abrupt shift in state of the atmosphere-ocean-cryosphere-land system, the current trend signifies an abrupt shift in state of the atmosphere, accelerating since the mid-20th century. Terms such as *climate change* and *global warming* no longer reflect the extreme nature of the climate events consequent on this shift, amounting to a climate catastrophe on a geological scale.

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