Response to Marks (2025): *Contemporary global warming versus climate change in the Holocene*

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A b s t r a c t. The Holocene geological record provides the most immediate context for understanding and interpreting the climate of the present and future Earth System. Marks (2025) suggests a Holocene climate steered largely by cyclical solar forcing, and that modern warming, driven by increased solar activity, will be replaced within the coming 3 kyr by cooling almost everywhere. This view contrasts with palaeoclimate data, instrumental records, an understanding of climate drivers and feedbacks, and global and regional climate modelling studies, which show that Holocene climate was largely controlled by slow Milankovitch-related changes. Superimposed on these were minor solar fluctuations with a higher frequency. Solar activity was at the same 'high' level in the 1780s, 1860s and 1980s, making it a highly unlikely cause of recent warming. Modern global warming has two main drivers: 1) anthropogenic greenhouse gases, which rose steeply after 1950; and 2) both water vapour, which increases as the ocean warms, and clouds. Atmospheric CO_2 levels are higher than at any other time since the Middle Miocene, making global temperatures warmer than any multi-century interval since the Last Interglacial. Earth's climate has left its equable Holocene state. The long residence time of CO_2 ensures persistent warming for tens of millennia.

Keywords: *Holocene, carbon dioxide, global temperature, climate models, proxy-based reconstructions*

Contemporary global warming, driven by anthropogenic greenhouse gas emissions, began a substantial rise in the late 1970s and continues unrelentingly. Evidence from the geological past is vital in understanding the relationship between climate change and greenhouse gases (GHGs), especially CO_2 which persists for millennia in the atmosphere and ocean (Talento, Ganopolski, 2021; Summerhayes *et al.*, 2024; Talento *et al.*, 2024). The changing composition of Earth's atmosphere along with many other climate signals is uniquely recorded in Antarctic ice cores extending back over 800,000 years, far beyond the 11,700 year history of the Holocene, our present interglacial. These records show that glacial–interglacial cycles are paced by insolation controlled by orbital cyclicity. CO_2 levels nonetheless rise during the initial increases in insolation just before an interglacial, released from the warming ocean surface, and act as a powerful amplifier. Feedback from water vapour evaporated from the warming ocean further amplifies the warming signal.

The role and rise of CO_2 today are different. Insolation has been in decline since the Early Holocene owing to a near-synchronous precession minimum and obliquity maximum (Berger, Loutre, 2002). Northern Hemisphere insolation underwent a significant decline through the Holocene, leading to the perception that Earth was entering a neoglacial period (Crucifix, 2009). However, that was balanced by increasing insolation in the Southern Hemisphere (Crucifix, 2009).

It is the rapid rise in anthropogenic CO_2 emissions and other GHGs in the mid-20th century that have dramatically driven planetary warming since that time, with 2024 recorded as having been the hottest year on record, exceeding 1.5°C above pre-industrial levels (Copernicus, 2025); the oceans have absorbed most of the extra heat retained by the Earth (Cheng *et al.*, 2025).

Atmospheric CO_2 levels have now likely exceeded those at any other time in the past ~14 million years (Middle Miocene) including all Plio-Pleistocene peak interglacial

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CO_2 concentrations (Hönisch *et al.*, 2023), and considerable future warming is in the pipeline (Hansen *et al.*, 2023; Summerhayes *et al.*, 2024). Climate responses are nonetheless complex as illustrated for the Holocene Thermal Maximum where a global dataset of climate proxies reflects a heterogeneous response to climate forcing (Cartapanis *et al.*, 2022) – geological evidence from one locality or region cannot be assessed in isolation.

Against this backdrop of extensive geological evidence, instrumental records and modelling, Marks (2025) proposes a mechanism for Holocene climate largely steered by cyclical solar forcing in which contemporary warming will be replaced within the coming 3 kyr by lower temperatures almost everywhere. Given the unorthodox views presented in Marks (2025), claiming to represent *the current state of knowledge of climate change in the Holocene*, we offer a critique of selected statements from his work that raise particular concern. We end with a short summary of our comments.

1. Anthropogenic global warming has been: *primarily postulated by the Intergovernmental Panel on Climate Change (IPCC)*.

Contrary to Marks's view (above), this topic has a long history of scientific research and was not primarily postulated by the IPCC. The IPCC has certainly been a consistent and unifying voice since releasing its first report in 1990. But, in the mid-19th century, between 1859 and 1872, John Tyndall (1861, 1864) had devised experiments which showed that CO_2 and other GHGs (notably CH_4 and water vapour) could allow visible light to pass through them unhindered – but that these gases trapped significant amounts of invisible infra-red radiation, i.e. the kind that is radiated by the Earth after it has absorbed sunlight. Slightly earlier, Eunice Foote (1856) had conducted a very much simpler experiment showing that CO_2 did absorb heat. Both Foote and Tyndall realized that this effect would warm the atmosphere, and Tyndall (1861) surmised that past changes in CO_2 in the air could explain much of Earth's climate history. As explained by Berner and Maasch (1996) these experiments confirmed theoretical explanations by Ebelmen (1845) of the role of CO_2 in the climate system. Subsequently, the effect of changing CO_2 on global temperature was investigated in the first climate model, by Arrhenius (1896, 1908).

The rise in CO_2 in background air away from industrial sources was documented by Callendar (1938, 1949, 1958). With the advent in the 1950s of high-resolution studies of the parts of the light spectrum affected by CO_2, the effects of this gas on climate were documented by Plass (1956a, b, c; 1959, 1961: see also Pierrehumbert, 2011). In 1957 Revelle and Suess drew attention to the "vast geophysical experiment" being performed on the atmosphere by the emission of CO_2. Revelle, Broecker and others brought this to the attention of U.S. President Johnson in 1965 (Revelle *et al.*, 1965).

Manabe and colleagues followed this with numerical models of the response of the atmosphere to rising CO_2 emissions (Manabe, Wetherald, 1975; Manabe, Stouffer, 1980). Broecker drew attention to the problems of global warming in 1975 (Broecker, 1975), followed by Augustsson and Ramanthan (1977). Flohn highlighted the issue at the first World Climate Conference in 1979 (Flohn, 1979). That same year Charney led a study of the issue by the US National Academy of Sciences (Charney *et al.*, 1979), confirming the relationship between CO_2 and temperature, and Ramanathan provided further data on the seasonal and regional effects of rising atmospheric CO_2 on temperature (Ramanathan *et al.*, 1979).

In 1980 Manabe and Stouffer investigated the sensitivity of the atmosphere to a rise in CO_2 confirming this understanding, and the US Department of Energy carried out a comprehensive review of the research still needed to study the further effects of CO_2 on climate as emissions increased with time (USDOE, 1980). In 1981, Hansen and colleagues examined and verified these effects and suggested a rise of 2.8°C for a doubling of atmospheric CO_2, a rise known as the *climate sensitivity* (Hansen *et al.*, 1981). Revelle reviewed the issue in Scientific American in 1982, alerting the reading public to the likely increase in warming if emissions continued (Revelle, 1982), and a 1983 review by the US National Academy of Sciences topic confirmed concerns about the potential impacts on society of the CO_2-temperature relationship (NAS, 1983).

In 1984, Hansen and colleagues further reviewed the evidence for climate's sensitivity to CO_2 emissions (Hansen *et al.*, 1984). An international conference on the topic was subsequently held in Villach, Austria in 1985, reported by the World Meteorological Organization (WMO) in 1986, which added to concerns about the warming calculated from increasing CO_2 (WMO, 1986).

These and other background reports on the topic were reviewed by the 10th Congress of the WMO in 1987, which recognized the need for a regular international review of the CO_2 problem. That concern led in 1988 to the establishment of the Intergovernmental Panel on Climate Change (IPCC) under the aegis of the WMO (a United Nations agency) and the United Nations Environment Programme (UNEP; see Warde *et al.*, 2018: Chapter 1). The IPCC delivered its first report in 1990, and further scientific agreement on the topic led in 1992, at the UN Earth Summit in Rio, to the formation of the UN Framework Convention on Climate Change.

2. *The climate models* [used by the IPCC] *have not been verified by their application to reconstructions of past climate changes and this makes the IPCC-presented climate change forecasts unbelievable*.

This statement by Marks (2025) is factually incorrect. In the First IPCC Assessment Report (1990), reference to climate previous to the last century was absent, but in the Fourth Assessment Report (2007) palaeoclimate information was already compiled into a single chapter (Caseldine *et al.*, 2010). The IPCC (2021) includes extensive evaluations of modelled past climate temperature change by comparing their output with palaeoclimate proxies (e.g., IPCC, 2021: section 3.3.1.1.1). The past climate intervals focussed on by the IPCC range back to the Paleocene–Eocene Thermal Maximum (55.9–55.7 Ma), and include, *inter alia*, the last deglacial transition (18–11 ka), the mid-Holocene (6.5–5.5 ka) and the last millennium (850–1850 CE), with syntheses of both proxy-based and modelling studies and in all cases extensive reference to published studies. The IPCC does not itself carry out climate modelling studies. Instead it uses the published results of numerical models applied to past climate conditions by the wider research community, so as to establish the utility of climate models for understanding present and possible future climates (see IPCC, 2021: p. 295 for a summary). Because the models work well on past and present time slices, the IPCC is confident that they will apply equally well to future time slices.

3. *The curve of reconstructed temperature in the last millennium of the Northern Hemisphere, prepared by Mann* et al. *(1998) and reproduced by IPCC (2001), obtained the nickname 'the hockey stick' after its shape. This temperature curve was heavily criticized both for major deficiencies in its paleoclimatic proxies and statistical methods used to construct it.* […] *Despite its unreliability, 'the hockey stick' was included in the last report of IPCC (2021), and it is also frequently and thoughtlessly reproduced to this day by climate alarmists and media.*

This claim by Marks (2025) is not true. Following the original study by Mann *et al.* (1998), several research organizations expanded on this work to demonstrate beyond question that while some of the statistics in the Mann *et al.* (1998) paper may have been weak, there really has been a sharp increase in temperature with time (e.g., Esper *et al.*, 2002; Moberg *et al.*, 2005; Jansen *et al.*, 2007; Wanner *et al.*, 2008; Ljungqvist *et al.*, 2012; Marcott *et al.*, 2013; PAGES Consortium, 2013; Neukom *et al.*, 2019). This rise has become increasingly obvious, with the last 10 years being the warmest 10 years in the observational record, i.e. each year of the past decade individually being warmer than any individual recorded year prior to 2015 (NASA, 2025; also see Hansen *et al.*, 2023). IPCC (2021) did not reproduce or cite the original *hockey stick* curve but did include graphs based on the latest available data and showing changes in global surface temperature for the past 2000 years (see Fig. 1).

As we write, this global average trend led to 2024 being the warmest year yet recorded (Copernicus, 2025). And we note that polar temperatures (especially in the Arctic) tend to be at least double the global average, helping to melt ice and reduce albedo (Rantanen *et al.*, 2022).

4. *Geological reconstructions show that rises and falls in the temperature on the Earth are dependent on the sunspot cycles.* […] *Parallel to a record of solar activity, 1000-year temperature cycles have been traced back through the Holocene.* […] *A solar forcing mechanism as a steering force for the Holocene climate change, expressed by the Bond Events (Bond* et al.*, 1997, 2001), has been completely neglected by the IPCC (2001).*

Contrary to Marks' statement (above) changes in the Sun's output over the timescale of the Holocene are considered by the IPCC. And the IPCC did not neglect the studies of Gerard Bond. In their 2021 report, and in more recent studies too, the significance of solar variability is considered to be relatively modest (IPCC, 2021). Furthermore, solar variability cannot be a significant factor in the sharp and continuing warming of the Earth in the late 20^{th} and early 21^{st} centuries, a period during which solar variability has continued without showing any significant upward trend (Clette *et al.*, 2014) (Fig. 2). Indeed Matthes *et al.* (2017) found changes in solar irradiance, while small, to have been slightly negative overall since ~1980. Global measurements of surface level solar irradiance date back to 1957–1958 whereas satellites have been measuring top-of-atmosphere irradiance since 1959.

The changes focussed on by Marks are sunspot cycles, which have an ~ 400-year observational record that shows clear 11-year cycles; these cluster into subtler patterns which show approximately century-scale rises and falls in maximum sunspot numbers (Steinhilber *et al.*, 2012; Clette *et al.*, 2014). Times of fewer sunspots are associated with a slightly lower solar energy output, and the *Maunder minimum*, a time of almost no sunspots in ~1650–1715, has

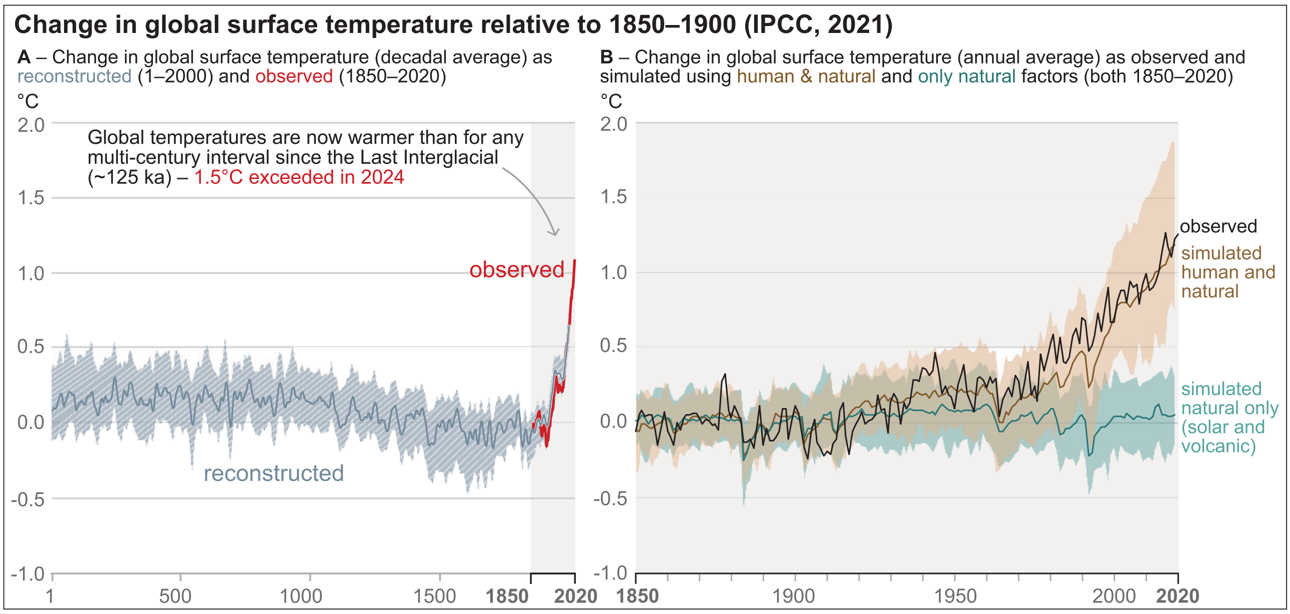

Fig. 1. Changes in global surface temperature relative to 1850–1900: **A** – Reconstructed from palaeoclimate archives (solid grey line, years 1–2000) and from direct observations (solid red line, 1850–2020), both relative to 1850–1900 and decadally averaged. The grey shading with white diagonal lines shows the very likely ranges for the temperature reconstructions. This is the 2021 version of the 'hockey stick' curve; **B** – Changes in global surface temperature over the past 170 years (black line) relative to 1850–1900 and annually averaged, compared to Coupled Model Intercomparison Project Phase 6 (CMIP6) climate model simulations of the temperature response to both human and natural drivers (brown) and to only natural drivers (solar and volcanic activity, green). Solid coloured lines show the multi-model average, and colour shades show the very likely range of simulations (Modified from fig. SPM.1 in IPCC, 2021)

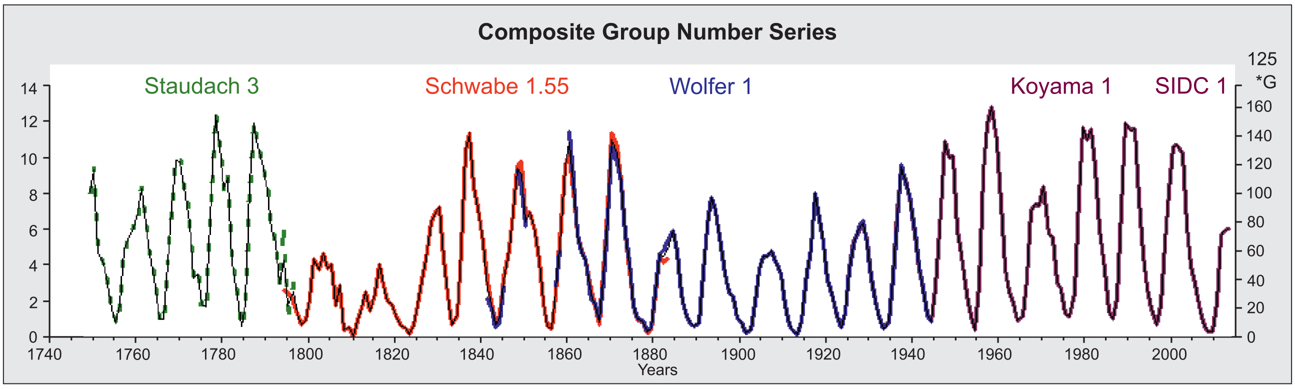

Fig. 2. A composite record of the yearly mean number of sunspot groups, back to 1749, derived from the four backbone periods represented by the four colours. The numbers in colour to the right of each backbone designation indicate the scale factor applied to each *raw* backbone to harmonize it to the Wolfer scale. The right-hand scale depicts an *equivalent* group number of sunspots (modified from fig. 28 in Clette *et al.*, 2014; see Clette *et al.* for details)

commonly been linked with the Little Ice Age, although the relation is not straightforwardly causal as this climatic episode had started some two centuries previously and continued to ~1850. In fact, the *Little Ice Age* contained several short warm periods when sunspots were at a maximum (Steinhilber *et al.*, 2012). It seems highly likely given the new sunspot calibration of Clette *et al.* (2014) that the mid- to late 20th century warming centred on 1980 was yet another of these *Little Ice Age* warm episodes (e.g., no different from that in 1780 – see Fig. 2) superimposed on warming supplied by expanding emissions of anthropogenic greenhouses gases (Summerhayes, 2017).

For earlier times and extending back through the Holocene, sunspot cycles and solar output have been reconstructed from cosmogenic evidence preserved in ice cores (in the form of ^{10}Be and ^{14}C signals), the analysis of the resulting patterns producing the inferred centennial- and millennial-scale cycles enumerated by Marks (e.g. Steinhilber *et al.*, 2012). However, this cosmogenic record reflects not just changing solar output but also changes in the Earth's geomagnetic field, and this latter factor has been considered responsible for millennial-scale cyclicity such as the 2300-year Hallstatt cycle, implying that on millennial timescales solar activity does not vary significantly (Nilsson *et al.*, 2024). Moving towards the present, the amplitude of sunspot cycles has been generally decreasing since 1980 (Clette *et al.*, 2014), with consequent overall reduction of solar activity, which should by Marks' logic lead to an overall cooling trend – and yet climate has warmed since 1980 by ~1.0°C. Furthermore, the revised sunspot data of Clette *et al.* (2014) demonstrate that sunspot numbers reached the same high level in the 1980s as they did in the 1780s and 1860s, when the average global temperatures were considerably cooler than they are today or were in the 1980s. Variations in solar output therefore cannot be driving the modern global warming that has ramped up progressively since the pre-industrial era, i.e. from 1850–1900.

There is no doubt that there were centennial/millennial-scale fluctuations of climate in the Holocene. As Magny (2007) demonstrates in the European setting, the cool periods (ascertained from ^{14}C and ^{10}Be signals) correlate with humid periods determined from lake levels, and with the ice rafting in the North Atlantic identified by Bond *et al.* (2001). Much the same patterns have been reported in more distant regions such as the western Mediterranean (Ait Brahim *et al.*, 2019; Zielhofer *et al.*, 2019) and China (Fan *et al.*, 2019; Tan *et al.*, 2020). Careful analysis suggests that the modest fluctuations in climate during the Holocene did not form the regular global pattern as suggested by Marks, but rather varied in time and space. Indeed, some of these fluctuations may correlate with volcanic activity rather than with solar activity (Sigl *et al.*, 2015, 2022). Nevertheless, the European evidence clearly does indicate a correlation between climate and solar events (Magny, 2007), even though the absolute temperature variations were likely small, as implied by a comparison between Figs. 1 and 2.

Overall, globally coherent and substantial climate excursions, such as the marked 8.2 ka event used to recognize the Lower/Middle Holocene subseries boundary (and thought to result from the outbreak of an ice-dammed lake's water into the Arctic Ocean), are seen in this context as rare. Indeed, the 4.2 ka event of the Middle/Upper Holocene boundary, is regarded as *not remarkable in the context of Holocene climate variability* (McKay *et al.*, 2024). A detailed study of the climate fluctuations of the last two millennia finds only the last century showing a globally coherent warming pattern (Neukom *et al.*, 2019).

Notwithstanding these fluctuations, the relative overall stability of the Holocene climate system prior to industrialization is underscored by the stability of Holocene sea level (and therefore of the overall mass of the cryosphere) after 7 ka BP, once the main phase of ice melt and post-glacial sea rise had ended (Clark *et al.*, 2016), and especially after 3 ka BP, when global sea level may have varied by as little as 0.1 m (Onac *et al.*, 2022). This stability ended in the 20th century, with current rates of global sea-level rise now approaching 5 mm/year, having doubled in the last three decades (Hamlington *et al.*, 2024).

5. *These IPCC projections were created by climate models, based on the assumption that the modern temperature rise is steered exclusively by the increasing content of human-induced CO_2 in the atmosphere while the role of water vapour as a greenhouse gas is neglected.*

Contrary to Marks' opinion, it is not true that the IPCC ignores water vapour as a GHG. In IPCC (2021) there are hundreds of references to its action, including stating (p. 178) that it accounts for ~75% of the terrestrial greenhouse effect and discussing its fluctuations (p. 305). Indeed water vapour is explicitly shown in figure AR6 TS17 of IPCC (2021). The IPCC also emphasized (p. 178) that water vapour has a residence time in the atmosphere of some 8–10 days, and thus all of the water vapour in the atmosphere – equivalent to a 2.5 cm-thick layer around the Earth – is rained out and replenished about 40 times a year (NASA Earth Observatory, 2010). This process is a complex one, with atmospheric humidity levels highly variable in time and space, and *inter alia* producing clouds which can either trap heat or reflect it depending on their form. Overall, as global temperature rises, more water evaporates allowing air to hold more water vapour, by 7% per degree rise in temperature. As global temperatures have risen sharply since 1970, a consequent rise in the water vapour content of the troposphere has indeed been observed, by about 1% per decade (Allan *et al.*, 2022). Water vapour acts responsively, as an amplifier of planetary temperature, the level of which is determined by long-lived, non-condensing, well-mixed GHGs such as carbon dioxide, methane and nitrous oxide. Schmidt *et al.* (2010) calculated that the CO_2 contribution to global warming amounted to 20%, the remainder mostly coming from water vapour and clouds. The influence of clouds means that this amplification is not simple: for instance, the persistence in 2024 of the record high global temperatures of 2023 – even as El Niño conditions waned in the latter half of 2024 – has been ascribed to a feedback mechanism leading to fewer reflective low-level clouds producing a lower global albedo and thus enhanced warming (Goessling *et al.*, 2025). Evidently, although CO_2 has a small concentration its effect is large because neither oxygen nor nitrogen, the main gases of the atmosphere, affect the passage of infrared radiation.

6. *Successive climate projections of the Intergovernmental Panel on Climate Change are based on the assumption that the modern temperature rise is steered exclusively by the increasing content of human-induced CO_2 in the atmosphere. If compared with the observational data, these projected temperatures have been highly overestimated*.

This statement by Marks (2025) is in error. The IPCC's projections incorporate 1) the effects of CO_2 and other GHGs (including water vapour), which act to increase global warming, along with 2) the effects of aerosols that act to decrease the warming signal by reflecting solar energy, and 3) the effects of changing land use (IPCC, 2021: p. 562) which may exacerbate warming through changes in albedo (e.g., replacing forests with grassland). Comparisons of the observational data with the modelled data on the global warming average through time show that the two are in close agreement (figs. TS.7 and TS.8 and SPM.1B in IPCC, 2021). Given this agreement, it is entirely reasonable for the IPCC to project possible changes through time based on different CO_2 forcings, and their forward projections from the observed and simulated data are realistic and not overestimated. The IPCC provides a range of possible climate projections based on a range of social parameters affecting CO_2 emissions. Although it could be argued that the higher of the suggested forward trajectories is the least realistic, the final outcome will ultimately depend on the level of emissions. The IPCC is also well aware that CO_2 is not the only greenhouse gas, and that aside from water vapour acting as a feedback, CH_4, N_2O and the CFCs are also important minor GHGs (IPCC, 2021: fig. TS.15).

In 2023–2024 observed global temperatures have indeed departed slightly above IPCC projections – but in a pattern that shows these projections as underestimates and not overestimates (Tollefson, 2025). The Earth warmed by significantly more than expected in 2023, and retained that warmth in 2024 even though a (modest) warmth-inducing El Niño gave way to a cool-inducing La Niña climate mode (Schmidt, 2024). This 2023–2024 warming has been correlated with an observed narrowing of tropical cloud belts, decreasing the Earth's ability to reflect sunlight: an unanticipated positive feedback on an overall warming world. Thus, while the IPCC projections are not a precise guide to the extent and course of global warming, they currently seem conservative rather than *highly overestimated*.

Hence, the assumption of Marks that changes in the Sun's output are decisive, and his consequent prediction that *In the coming 3 ka, lower temperatures are expected everywhere, except for the intertropical zone where higher winter temperatures are expected* is wholly inconsistent with the scientific evidence from both modern and palaeoclimatic perspectives. In suggesting that the burning of fossil fuels is essentially irrelevant to present and future climate, his stance runs counter to both experiment and the mainstream scientific literature, including IPCC reporting, and, furthermore, undermines the efforts being made to make our lives less reliant on this convenient, but dangerous, energy source. This issue is far from an academic one and should be informed, as he notes, by the best available science.

SUMMARY

Much of the above-quoted misinformation in Marks' article relates to the activities of the IPCC, which has experienced attacks on its credibility over its history (Bolin, 2007; Pedersen *et al.*, 2022). Past criticisms of its assessment reports include issues of methodology, and such critiques have prompted necessary improvements over time and enhanced the quality and relevance of its reports (O'Reilly *et al.*, 2024). It is also abundantly clear that the fossil fuel industry and its supporters have muddied the waters as far as the role of fossil fuel burning in global warming is concerned (Oreskes, Conway, 2010).

Marks nonetheless draws important attention to the geological record of the Holocene, as it is the most immediate context for understanding and interpreting the present and future Earth System in its many aspects, of which climate is but one. That the Middle Holocene was slightly warmer than the pre-industrial Late Holocene, and with less ice cover, seems clear and was described and discussed in detail by the IPCC (2021), though the distribution of its warmth in time and space was complex (Cartapanis *et al.*, 2022). Overall, the changes in Earth's climate from Early to Late Holocene are consistent with slow Milankovitch-related changes in insolation patterns (Crucifix, 2009).

There do remain some long-standing discrepancies suggesting continuing knowledge gaps. In particular, models considered by IPCC (2021) underestimate the magnitude of African monsoon precipitation during the Early–Middle Holocene, although new modelling of North African humid periods over the past 800,000 years now provides good agreement with proxy records and confirms the strong role of orbital precession amplitude (Armstrong *et al.*, 2023).

The IPCC acknowledges some underestimation of the variability of the Atlantic Meridional Overturning Circulation (AMOC) in model reconstructions. Nonetheless, there is generally strong agreement between proxy-based reconstructions and models, such as for Northern Hemisphere mean temperatures; and where discrepancies do exist these can often be explained by noisy proxy data that can be improved by enhanced data quality and spatial coverage (Neukom *et al*., 2018).

When Early to Middle Holocene climate is considered in detail, some discrepancy exists between proxy-based reconstructions that commonly suggest somewhat warmer temperatures, and climate model reconstructions that propose slightly cooler conditions; this has been referred to as the *Holocene global temperature conundrum* (e.g., Liu *et al*., 2014; Bova *et al*., 2021; Kaufman, Broadman, 2023). Careful consideration of the data suggests a bias of the proxy data towards summer conditions because many of these data come from land or marine organisms that grow preferentially in the spring and summer. The model data include what we know from calculations of Earth's orbital precession and axial tilt, the variables that govern long slow changes in our climate (e.g., Crucifix, 2009), but climate models are being progressively refined to include newly recognized influences on climate forcing, such as substantial GHG emissions from deep Arctic lake sediments (Freitas *et al*., 2025), while climate proxy-based reconstructions need adjustment to make them more annually representative, e.g. by correcting for a common bias towards summer data. A recent assessment of this conundrum (Kaufmann, Broadman, 2023) suggests that there was a *relatively mild* mid-Holocene thermal maximum. The earliest Holocene might have been warmer based on orbital data, but for the fact that Northern Hemisphere ice sheets did not completely melt away until 7 ka, keeping the climate cooler than it might have been in their absence. Under the circumstances, the IPPC (2021: p. 61) is justified in claiming that, more likely than not, the *latest decade [2011–2020] was warmer than any multi-century period after the Last Interglacial, around 125,000 years ago*.

Notwithstanding the requirements for further refinement of both proxy and model data from the Holocene, it is clear that Earth's climate departed from its Holocene state in recent decades, as part of the wider Earth System changes that prompted the suggestion that we have left the Holocene and entered an Anthropocene epoch (Steffen, in Robin *et al*., 2013). Given that the trend of warming continues to be upward, and with more warming in the pipeline (Hansen *et al*., 2023), there is a serious risk of long-term warming that would bring Earth's climate close to temperatures typical of the early Late Pliocene about 3 million years ago, when Greenland lost its ice sheet, the West Antarctic Ice sheet disappeared and the East Antarctic Ice Sheet contracted. These changes then led to significant measurable rises in sea level of ~10–12 m averaged globally. Hence continued warming has inevitable long-term consequences for both the planet and human civilization (Archer, Ganopolski, 2005; Ganopolski, 2016; Talento, Ganopolski, 2021; Summerhayes *et al*., 2024; Wunderling *et al*., 2024), largely due to the continued burning of fossil fuels (see also the statement on climate change of the Geological Society of London – Lear *et al*., 2020). The associated risks of triggering irreversible self-perpetuating changes in the Earth System (Scheffer *et al*., 2009; Lenton *et al.,* 2019; Armstrong *et al*., 2022) should encourage a level of caution lacking in Marks' analyses. The time to move away from fossil fuels to newer forms of energy is long past due, as comparison of the present climate state with the long-term Holocene record shows.

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The work was received by the editorial office on 20.03.2025
Accepted for printing on 24.03.2025