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Response to Dąbski (2025): *Global climate change, CO_2 and climatic catastrophes*

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Abstract. Dąbski (2025) challenges the conventional understanding of climate change in asserting that atmospheric carbon dioxide has not strongly influenced global temperatures in the geological past or present. He claims that other factors including solar irradiance, oceanic oscillations, and changes in atmospheric aerosols explain much of the warming documented since pre-industrial times; and that current climate trends are not a matter of urgent concern. These views expand upon those by Marks (2025) to which we have already responded (Summerhayes et al., 2025). We refute these views and correct a common misunderstanding: atmospheric carbon dioxide was a powerful amplifier, not trigger, of global warming during past glacial–interglacial cycles (the trigger was Milankovitch forcing). In contrast, contemporary global warming has over-ridden Milankovitch forcing, being driven directly by anthropogenic greenhouse gas emissions, notably carbon dioxide which continues to accumulate in the atmosphere and oceans, locking global temperatures and its derived effects (e.g., sea level, extreme climate events, biological consequences) into a long-term upwards trajectory.

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

Dąbski (2025) offers a commentary on climate change science, in part following the article of Marks (2025), that challenges the mainstream scientific consensus on contemporary global warming and to which we have already replied (Summerhayes *et al*., 2025). Dąbski, too, refutes the leading role of anthropogenic carbon dioxide emissions into the atmosphere in climate change, suggesting that contemporary climate trends are not a matter of urgent concern. He proposes alternative naturally occurring phenomena to support his view.

Nonetheless, widely available scientific evidence continues to support, and indeed strengthen, the mainstream consensus that global warming is being driven directly by anthropogenic greenhouse gas emissions. Among the most recent repudiations of this mainstream consensus, we note a report written by a 5-person Climate Working Group published on 23 July 2025 by the US Department of Energy (DOE) (Christy *et al.*, 2025). This report attracted swift criticism from Cleetus *et al*. (2025), Whitehouse and Murray (2025), and most notably 86 expert climate scientists in their own 453-page review (Dessler, Kopp, 2025). While refraining from a detailed critique of the DOE report, we observe that it strategically replaces outright denial of anthropogenic global warming with scepticism (admitting that global warming is occurring, but portraying it as far less troubling than shown by mainstream climate science bodies; see Oreskes, Conway, 2010a, b). Our view is consistent with that of Dessler and Kopp (2025).

Here we present a detailed critique of Dąbski's main claims, which resemble those that frequently appear in media outlets that promote climate scepticism and denialism. Our comments, below, augment those already made by Summerhayes *et al*. (2025).

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1. Nobel Prize winners and other scientists have denied that CO_2 increases cause climate change.

Dąbski notes that a few Nobel scientists (citing John Clauser and Ivor Giaever) do not believe that CO_2 plays a role in global warming. However, John Clauser's expertise lies in quantum mechanics and Ivor Giaever's in superconductors, subjects completely unrelated to climate science. By contrast, Paul Crutzen, Mario Molina, Syukuro Manabe, Klaus Hasselmann and Sherwood Rowland, all Nobel laureates for ground-breaking atmospheric chemistry and physics research, emphasized the dangers of global warming through the emission of greenhouse gases. To whom are we to give more credibility?

More widely, Dąbski does not acknowledge the scientific credentials of the many authors of the reports of the Intergovernmental Panel on Climate Change (IPCC), nor the extensive prior science that led to the formation of the IPCC (e.g., Manabe, Wetherald, 1975; Charney *et al*., 1979; see Weart, 2008), nor widely quoted statistical analyses of the peer-reviewed scientific literature suggesting between 97 and 99% agreement that climate is changing as a result of human activities (Cook *et al.*, 2013; Powell, 2015; Lynas *et al*., 2021). Nor does Dąbski mention that the satellite research of award-winning climate sceptic John Christy, lead author of the 2025 DOE report (above) and whom Dąbski credits with helping to weaken the scientific consensus, "does not cast doubt on the reality of long-term anthropogenic warming" (Santer *et al.*, 2017, p. 484). Judith Curry, who Dąbski also mentions, is another author of that report and like Christy is closely linked with fossil-fuel policy advocacy (Whitehouse, Murray, 2025).

French physicist Joseph Fourier introduced, in 1827, the concept of the greenhouse effect, recognizing that the Earth's atmosphere traps heat and keeps the planet warmer than it would be otherwise. Soon after, initial evidence for CO_2-induced warming came from experimental work by Foote in the USA (Foote, 1856) and Tyndall in the UK (Tyndall, 1861), with Arrhenius (1896) in Sweden being the first to quantify the link between rising CO_2 levels and global temperature increases.

However, for almost 100 years the absorption spectrum of CO_2 remained largely unknown in detail, which made it difficult to determine its effects quantitatively. This shifted abruptly in the early 1950s, during the Cold War, when several new developments changed the understanding of greenhouse gas agency. In Scandinavia, scientists under the leadership of meteorologist Carl-Gustaf Rossby at Stockholm University started measuring CO_2 in a wide network of monitoring stations, and linked the gas to global warming (Bohn, 2011). Also, the US military wanted to know if CO_2 in the atmosphere would block infrared radiation from Soviet jet engines, which could prevent heat-seeking missiles from hitting their targets. An ultra-high-resolution spectrometer was built for this research at Johns Hopkins University, with military funding, and led to the full identification of the CO_2 spectrum. Although the results were initially classified, Gilbert Plass presented them orall and in a series of research papers to establish the greenhouse gas effect of CO_2 in the atmosphere (e.g., Strong, Plass, 1950; Plass, 1956a, b). Later he drew the public's attention to the CO_2 and climate question in a paper published in Scientific American (Plass, 1959).

All data on the effects of CO_2 on the atmosphere are stored in the High-Resolution Transmission Molecular Absorption (HITRAN) Database at the Atomic and Molecular Physics Division of the Harvard-Smithsonian Center for Astrophysics, from where they can be used by NASA and others to study the changing properties of the atmosphere, or to simulate and predict the effects of CO_2 and other greenhouse gases in the atmosphere. This is an example of a spinoff from military research adding value in the civilian science sphere.

Not long after Plass's work, John (later Sir John) Houghton would undertake his lengthy experiments with infrared radiation (Houghton, Smith, 1966), which led in due course to emplacement of a downward-looking radiometer on a space satellite. The resulting data clearly showed at what wavelengths CO_2 was blocking outgoing infrared radiation (hence warming the atmosphere). The counterparts to the satellite instruments are ground-based radiometers that look up through the atmosphere. These confirm that much of the blocked radiation is heading back towards Earth's surface to maintain atmospheric warming. More recently our understanding of radiation and climate has advanced significantly through studies of the climates of nearby planets, which have a great deal to teach us about how our own climate system works (Pierrehumbert, 2010, 2011). Dąbski (2025) (like Marks, 2025, whom he quotes) does not acknowledge these robust developments in fundamental physics.

Because of Houghton's experience in these matters, he was appointed to head the development of the first reports of the newly formed IPCC in 1988 (Bolin, 2007; Sörlin, Paglia, 2025). In 1990, he was instrumental in persuading the then UK Prime Minister Margaret Thatcher to approve the opening of the Hadley Centre for Climate Prediction and Research, within the UK's Meteorological Office. The Centre, like others dotted around the globe, is one of the main sources of information for any organization wanting accurate data about climate change. The findings of this and comparable governmental and university laboratories are used by agencies of the United Nations, in association with the world's space agencies, to develop annual public announcements on the state of the climate; among these organizations are the World Meteorological Organization (WMO), the United Nations Environment Program (UNEP), the Intergovernmental Oceanographic Commission (IOC), the Food and Agriculture Organization (FAO), and the Committee on Earth Observation Satellites (CEOS). Together with the relevant constituents of the International Science Council (ISC), these all contribute to the Global Climate Observing System on which scientists rely for policy-relevant knowledge about modern climate change.

This growing body of knowledge became a source of tension between the climate science community and powerful economic interests. For instance, Exxon, among other petroleum companies, has long been aware of the link between CO_2 emissions and global warming (Supran, Oreskes, 2017). Back in 1982, at a conference organized by James Hansen (NASA's Goddard Institute for Space Studies), and which was supported with a grant from the Exxon Research and Engineering Company (EREC), the EREC President, E.E. Davis, pointed out "that few people doubt that the world has entered an energy transition away from dependence upon fossil fuels and toward some mix of renewable resources that will not pose problems of CO_2 accumulation. The question is how do we get from here to there while preserving the health of our political, economic and environmental support systems?" (Davis, 1984). Davis was "upbeat about the chances of coming through this most adventurous of human experiments with the ecosystem" (Davis, 1984).

In subsequent reality, though, the petroleum and related geological communities worked to spread public doubt on the notion that burning fossil fuels, an activity at the core of the largest and most profitable industry of the last century, emits greenhouse gases that warm the planet (Oreskes, Conway, 2010a, b). ExxonMobil had an 'in-house' scientific understanding of climate change equivalent to that of researchers around the world. But they chose to publicly deny its implications, and sowed confusion about the authenticity and importance of this knowledge, by emphasising uncertainties, or denying internal scientific conclusions, or by promoting the idea of an impending ice age in public communications (despite the ExxonMobil climate scientists correctly rejecting this idea). The wide gap between ExxonMobil's private knowledge and public stance was exposed by Supran *et al.* (2023). They showed that climate projections by Exxon/ExxonMobil scientists between 1977 and 2003, of an average global warming of 0.20°C per decade, were comparable to those of mainstream academic models.

2. Climate sensitivity is uncertain.

There is indeed discussion over the scale of equilibrium climate sensitivity (ECS, the long-term global average temperature increase after CO_2 has doubled and a new energy balance is reached). However, in question is the ultimate severity of greenhouse gas-driven global warming, not whether it is happening. The IPCC (Fig. TS.6 in the IPCC's AR6 report of 2023) estimates this sensitivity to be on average 3°C, with a likely range of 2.5–4.0°C for a doubling of CO_2, mainly by using a modelling approach. In contrast, Hansen *et al.* (2023) proposed that ECS can be better estimated from palaeoclimate data, which points to a significantly greater sensitivity of 4.8 ±1.2°C, whereas Judd *et al.* (2024) suggested a yet higher value of 8°C consistently through the Phanerozoic. Bjordal *et al.* (2020) advised that an ECS of >5°C was plausible when considering cloud feedbacks. Myhre *et al.* (2025) assessed the various climate sensitivity estimates on the basis of the satellite-measured increase in Earth's Energy Imbalance (EEI) from ~0.5 to ~1.5 W/m^2 in the 2001–2023 interval, and deduced that this pattern better accords with the higher climate sensitivity estimates than with the more conservative figure from the IPCC. Moreover, Mauritsen *et al.* (2025) noted that EEI had reached 1.8 W/m^2 in 2023, which is twice the value predicted by climate models.

These values, though, are global averages. In reality, warming in the polar regions is between 2 and 4 times the global average figure (Rantanen *et al.*, 2022). Hence the average Arctic warming for the IPCC's estimated average global warming of 3°C (for a doubling of CO_2) will be between 6 and 12°C. If Hansen's (2023) estimate of an average of 4.8°C is correct, the Arctic will warm by between 9.6 and 19.2°C. And that is where much of the ice is located that will raise sea level when it melts. Much the same argument applies to the Antarctic, although its warming patterns do not precisely duplicate those of the Arctic – there is no warm current equivalent to the Gulf Stream/North Atlantic Current supplying heat to Antarctica.

Even accepting the conservative IPCC estimate, global warming represents a serious predicament. Of the extra heat being trapped by greenhouse gases (including water vapour) in the ocean-atmosphere system, >90% is now stored in the ocean. One of the clearest indicators of the warming of the last half-century is the large and now observationally well-constrained build-up of heat in the oceans, of some 450 zettajoules, accommodating some 93% of the total warming (Fig. 6a in Forster *et al.*, 2025) (for comparison, humanity's total energy consumption in a year is about half a zettajoule). For the planet's climate to reach an equilibrium across the air-sea interface, much of this ocean-stored heat will have to move slowly into the atmosphere over time.

3. The claim that current warming is unprecedented is not supported. And: Current warming is not unprecedented in either its magnitude or its dynamics.

Current warming is clearly unprecedented in the past 2000 years. Warming over the past decade, 2015–2024, of 0.27°C (Forster *et al.*, 2025), is certainly unprecedented since instrumental records began, making the Earth on average 1.24°C hotter relative to the pre-industrial (1850–1900) baseline temperature. This overall rise is not yet on the scale of that associated with the Pleistocene–Holocene transition of ~6°C over ~6,000 years, but has taken place an order of magnitude more rapidly, mostly in the last 70 years, when the pace of fossil fuel burning accelerated. Moreover, the whole Earth has warmed over this time, unlike the climate oscillations of the past two millennia, such as the Little Ice Age, the component temperature highs and lows of which were globally diachronous (Neukom *et al.*, 2014).

Further back, into the Late Pleistocene, marked millennial-scale oscillations characterized mid-glacial conditions, via a 'see-saw' pattern of temperature redistribution between the hemispheres that we do not see happening today. These found their greatest effect during the transitions from warm to cold climates typical of mid-glacial climates. In the Arctic they are known as the Dansgaard-Oeschger oscillations identified from Greenland ice cores, in which changes of temperature by up to about 10°C in as little as 50 years could be identified (Dansgaard *et al.*, 1984; Steffensen *et al.*, 2008). The latest of these was the Younger Dryas event, which extended from 12,900 to 11,700 yrs BP. The seesaw pattern was marked by gradual warmings in Antarctica coinciding with coolings in Greenland, followed by gradual coolings in Antarctica aligning with dramatic warmings in the Arctic as heat was transferred from one hemisphere to the other via the thermohaline circulation of the world ocean (Broecker, 1998; Stocker, 1998; Ahn, Brook, 2007). This same pattern applies to the Younger Dryas, in which northern hemisphere cooling and temporary glacial advance was matched by warming and glacial retreat in the Southern Alps of New Zealand (Barrows *et al.*, 2007; Kaplan *et al.*, 2010). These short-term fluctuations reflect ice-sheet instability during cold intervals of Earth's geological history. They are not comparable to the sharp and truly global warming of recent decades that is occurring in our present interglacial.

Much in the recent warming is unprecedented, and the measured, considerable increase in Earth's energy imbalance over this time (now exceeding ~1 watt/m^2) (Fig. 6b in Forster *et al*., 2025) indicates that warming will continue until equilibrium (the balance between incoming solar energy and outgoing infra-red radiation, or heat) is restored.

4. In the Pleistocene, CO_2 rise lagged temperature rise.

This criticism is often made, but ignores the various changes affecting Earth's climate during the Pleistocene. While one might simplistically expect cooling to reduce atmospheric CO_2, because this gas dissolves preferentially in colder water, to understand what is really happening one has to take into account positive and negative feedbacks. During times when ice dominated polar regions, changes in land-ice and sea-ice cover and in sea level led to lags between cooling and CO_2 abundance (as there was less sea area available in the cooling ocean to absorb CO_2). In contrast, during glacial terminations, CO_2 and temperature rose in synchrony as ice melted, sea level rose, water warmed and the sea area increased.

In the Late Pleistocene Antarctic ice core record, a close correlation between temperature and climate is clearly seen (Lüthi *et al*., 2008; Fig. 1). In that time interval, the main driver of climate change was the shifting patterns of sunlight on the Earth's surface caused by the Milankovitch (astronomical) cycles. Three greenhouse gases amplified this solar signal. Firstly, as the oceans warmed they released CO_2. Secondly, water vapour was evaporated from the warming ocean. Thirdly, warming wetlands released methane gas. In the well-documented Last Deglaciation, close synchrony of rising temperature and rising CO_2 has recently been demonstrated (Beeman *et al*., 2019), though with variable phasing reflecting the complex mechanisms involved.

During cooling cycles, lags in the correlation between atmospheric CO_2 and temperature were caused by physical feedbacks. As the world cooled, polar tundra expanded and northern hemisphere forests shrank, and thus plants absorbed less CO_2. Cooling was also exacerbated by the increased cover of reflective snow and ice. For example, as the North American Ice Sheet advanced south as far as the location of modern Kansas City, and the British-Scandinavian Ice Sheet advanced almost as far south as London and Berlin, the Earth's albedo (the reflection of solar energy) gradually increased and hence cooled the Earth (and at the same time reduced the areal extent for plant life to absorb CO_2). These interactions modulated the relation between the temperature and CO_2 signals during cooling periods (Summerhayes, 2020; Summerhayes *et al*., 2024), but the role of CO_2 as a climate amplifier is not in doubt (e.g., Beeman *et al*., 2019). Throughout the Late Pleistocene, CO_2 ranged narrowly between 280 ppm in warm periods and 180 ppm during glacial maxima. It now lies at 428 ppm (NASA, 2025a), a value similar to that at the height of the mid-Piacenzian warm period of the Pliocene, 3 Ma ago. CO_2, though, is not the only greenhouse gas. Adding the effects of methane and nitrous oxide for instance gives us the CO_2 equivalent (or CO_2eq), which NOAA calculated was 534 ppm in 2023 (NOAA, 2023); this would have a significantly greater impact on climate than CO_2 alone, something on which Dąbski did not comment.

5. The role of CO_2 in driving past changes in temperatures is debatable. There is no evidence that CO_2 was the triggering factor for global temperature changes. The past correlation between CO_2 and temperature was frequently negative.

A tight correlation between CO_2 and temperature is evident throughout the Middle and Late Pleistocene (Fig. 1). For pre-Pleistocene time, in which ice cores are not available as high-quality records of climate change, the close association between large-scale natural greenhouse gas emissions (CO_2/CH_4) and climate warming is still clearly evident. As a prime example, consider Snowball Earth. During Neoproterozoic time, two large glaciations covered the Earth's surface, each for several million years. During each glaciation, volcanic emissions of CO_2 increased in the

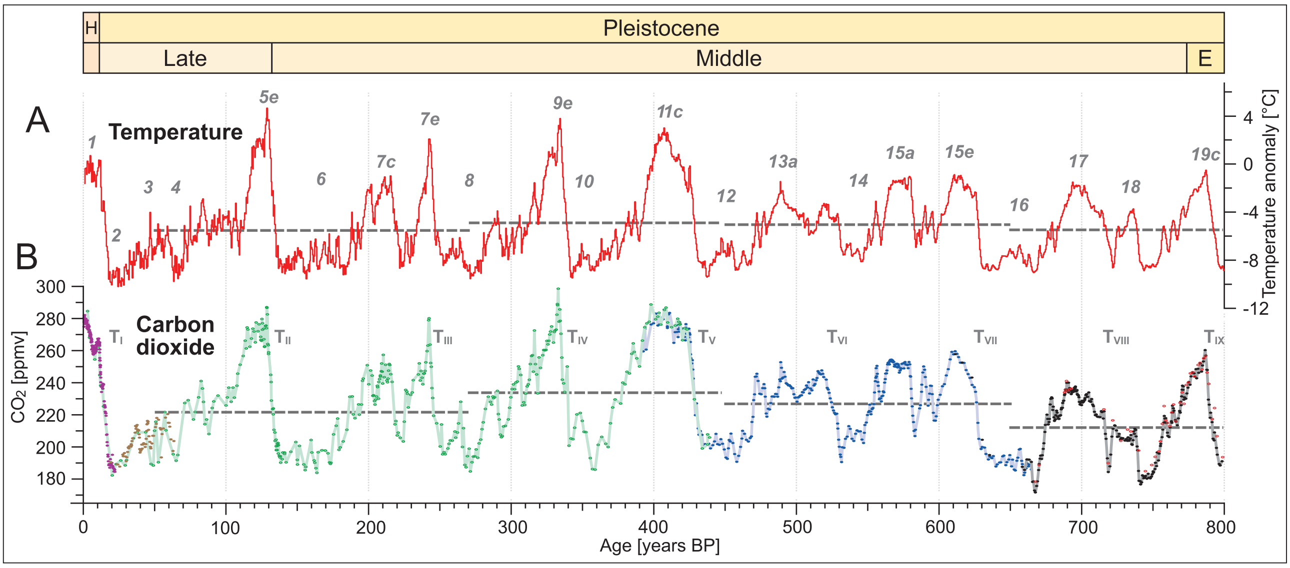

Fig. 1. Carbon dioxide and deuterium excess (a temperature proxy) records for the Antarctic EPICA Dome C ice core (δD_{ice}; Jouzel *et al*., 2007), showing a strong correlation between CO_2 and temperature over the 800 thousand year duration of the ice core. In detail, CO_2 slightly lags temperature which is forced by Milankovitch cyclicity, CO_2 serving as a powerful amplifier – in contrast to contemporary warming which is driven by anthropogenic CO_2 emissions. Glacial terminations (T_I–T_{IX}) and marine isotope stages / substages (1–19) are shown (Lüthi *et al*., 2008: Fig. 2, modified)

atmosphere, eventually warming it enough to terminate the glaciations (e.g., Xu *et al*., 2024). The abundant CO_2 in the atmosphere then led to the deposition, atop the glacial remains, of thick carbonate deposits. There is also ample evidence that CO_2 was abundant in the atmosphere during the so-called 'hyperthermal' warm periods of the Toarcian and the Paleocene-Eocene Thermal Maximum (e.g., Zachos *et al*., 2001; Cohen *et al*., 2007), and in the Cenozoic palaeoclimate pattern more generally (e.g., Burke *et al*., 2018; Zhu *et al*., 2019). An extensive review of the evidence for CO_2 during the Cenozoic was recently published by a consortium led by Bäbel Hönisch (The Cenozoic CO_2 Proxy Integration Project – CenCO$_2$PIP Consortium, 2023). It provides good evidence for higher Earth System sensitivity to raised levels of CO_2. There is a clear association between declining CO_2 and declining temperature through the Cenozoic, with strong links between these parameters and sea level, changes in plant coverage and evolutionary changes in animal development in adaption to vegetation changes.

We note that the 485 million-year-study (Judd *et al*., 2024) of most of the Phanerozoic Eon, quoted by Dąbski as evidence of a lack of correlation between CO_2 and climate, in fact came to the opposite conclusion: that CO_2 was the dominant driver of Phanerozoic climate – and that climate was more, not less, sensitive to its concentration than suggested by the IPCC.

Other controls on climate can complicate the association between temperature and CO_2. The most significant departure from the expected CO_2-temperature association occurred in Cretaceous time, as noted by Judd *et al*. (2024). At that time, excess production of basalt during seafloor spreading led to the percolation of CO_2-rich ocean water into new ocean crust and storage of CO_2 in Ca and Mg carbonates in sub-sea-floor basalts (Müller, Dutkiewicz, 2018). This is analogous to what is happening in modern Iceland with the human injection of CO_2 into deep basalt for carbon storage (CarbFix project). The Cretaceous ocean was quite unlike the modern one, because there were no major sources of ice at the poles. Under the extreme warmth of the Cretaceous climate, the ocean became hot, saline and poor in oxygen (Brass *et al*., 1982), rather than mostly cool and oxygen-rich at depth as it is now. This led to the development of more intense and expanded oxygen minimum zones than at present, where anoxic conditions encouraged the preservation of sinking planktonic organic remains, ultimately leading to the deposition of organic-rich sediment. This process was associated with the flooding of the continental margins to depths of some 75–250 m above present day mean sea level (Haq, 2014), which encouraged the widespread deposition of marine planktonic remains. These various processes helped trap CO_2 in the deep ocean, including during Cretaceous oceanic anoxic events (see Schlanger, Jenkyns, 1976; Arthur *et al*., 1987; Summerhayes, 1987; Trabucho-Alexandre *et al*., 2012).

Independent evidence for high CO_2 in the Cretaceous ocean is suggested by the raised height of the Carbonate Compensation Depth (CCD). The CCD level subsequently declined markedly from the Cretaceous through the Cenozoic as the CO_2 abundance in the atmosphere fell, likely in response to the chemical weathering of growing mountain chains (Pälike *et al*., 2012). Thus, physico-chemical and biological oceanic processes were indirectly controlling atmospheric CO_2 in the Cretaceous when an ocean enriched in CO_2 may have been associated with less than expected CO_2 in the atmosphere. This 'Mesozoic Conundrum' (Judd *et al*., 2024) has stimulated research to find an explanation. For instance, enhanced levels of atmospheric methane, a potent greenhouse gas, could plausibly have helped maintain Cretaceous warmth (Beerling *et al*., 2009; Wilkinson *et al*., 2012).

Dąbski has no need to explain Cretaceous climate by turning to Shaviv's extraterrestrial hypothesis, which suggests a control on Earth's climate by the passage of the solar system through the spiral arms of the galaxy. Examination of Cretaceous geology suggests a more robust and prosaic explanation, related to plate tectonic changes: these provide a major control on the carbon cycle through changes in volcanic CO_2 outgassing, and in CO_2 uptake as crustal and mantle rocks are altered. A doubling of mid-ocean ridge lengths took place starting 200 Ma ago, as Pangaea began splitting apart; these reached a maximum during the Early Cretaceous (143–100 Ma ago), before tectonic activity and corresponding CO_2 production decreased towards the Cenozoic. Superimposed on this broad trend, a 26–30 Ma tectonic cycle has been identified, linked to the dynamics of subduction. These various geological findings provide a more convincing explanation for the patterns observed than do Shaviv's mooted, but theoretically unjustified, galactic plane/solar system interactions (Müller, Dutkiewicz, 2018). Extraordinary claims, like Shaviv's, demand extraordinary evidence.

6. Models used by the IPCC disagree with current observational data.

The IPCC's climate models are tested at length against both palaeoclimate and modern climate data and reproduce them effectively. While the models are not perfect, they do provide useful information about past, present and likely future climate states, as discussed in detail in Summerhayes *et al*. (2024).

7. Solar irradiance can explain much of the warming since pre-industrial times.

Changes in solar irradiance, such as those linked with sunspot cycles (and their influence on cosmic rays and consequent effect on cloud formation), do have an effect on climate, but this has been shown to be a minor one throughout Holocene time (e.g., North *et al*., 2012). Their effects are extremely weak compared with the effects of the changes produced by Milankovitch cycles, like those shown in Fig. 1. Hence, we cannot look to solar radiation changes associated with sunspot cycles as a major control on climate.

Observational records of the sunspot cycle post-1750 demonstrate that sunspot activity (a proxy for solar radiation output) peaked at about the same level in three periods: the 1780s, the 1860s, and 1980–1990 (also see Fig. 28 in Clette *et al*., 2014). As the Earth warmed markedly in the last half-century, the peak amplitudes of the main 11-year sunspot cycle remained as they were in the 1780s and 1860s. We cannot, therefore, ascribe the warming post-1950 to an unusually active Sun (Fig. 2 in Summerhayes *et al*., 2025).

Dąbski asserted that the current sunspot cycle (25) was 'the strongest ever', but we now know this is wrong. At present we have passed the peak of sunspot cycle 25, which is modest, and smaller than most over the last half-century (Fig. 2). The average sunspot number for cycle 25 was 160, while that for 1960 was over 200 (Royal Observatory of Belgium Sunspot Index and Long-term Solar Observa-

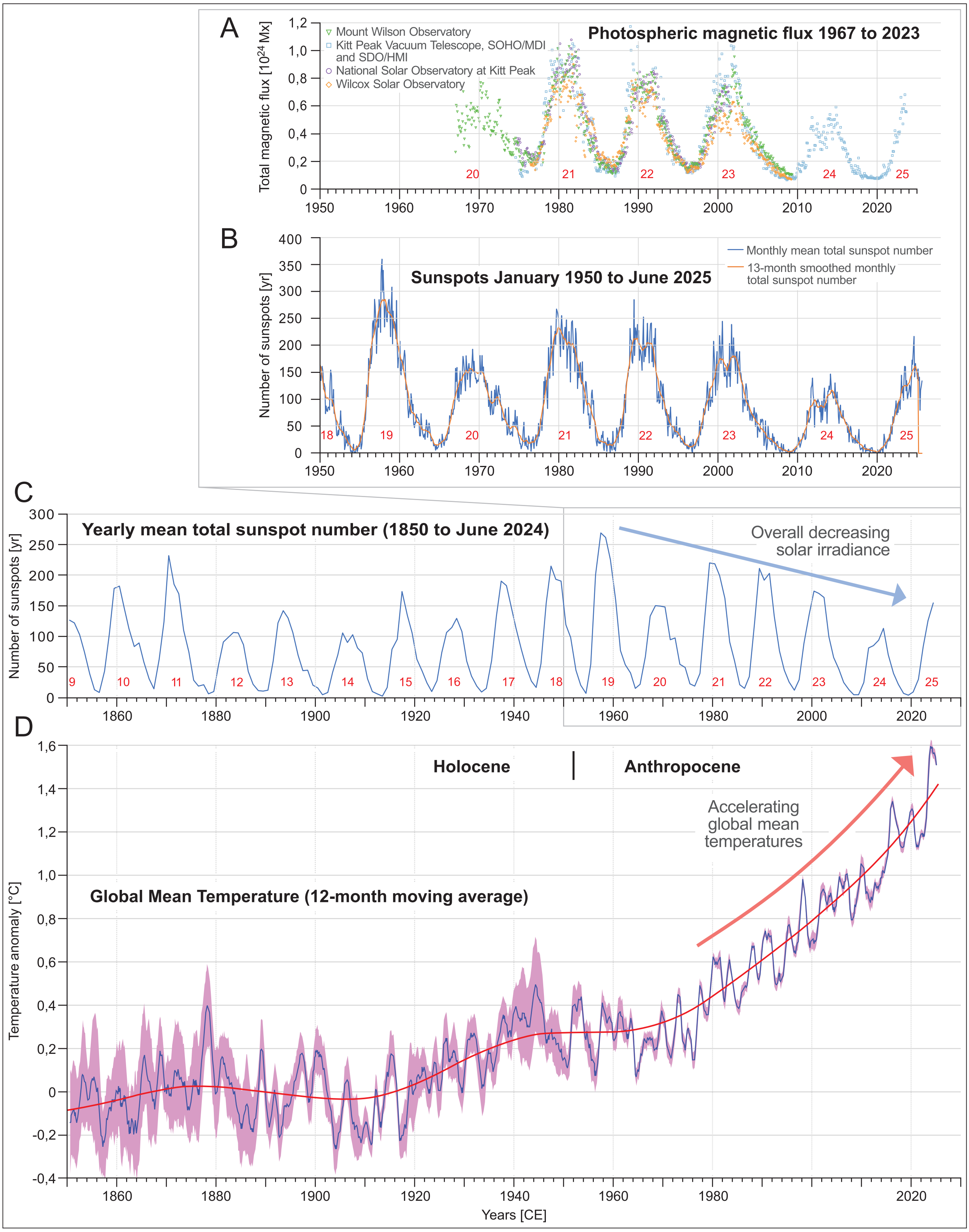

Fig. 2. Proxies for total solar irradiance (the total radiative energy of the Sun received by Earth's system, where: **A** – photospheric magnetic flux; **B**, **C** – sunspot observations compared with global mean temperature (**D**), showing overall declining solar irradiance as global temperatures accelerate from the 1970s onwards. **A** – solar total photospheric magnetic flux since 1967, which tightly synchronizes with satellite data and is a good independent measure of solar irradiance. Note that magnetic flux perfectly tracks sunspot intensity (**B**, **C**; Chatzistergos *et al.*, 2023: Fig. 2, modified). **B** – monthly mean total sunspot number, and 13-month smoothed monthly total sunspot numer (https://sidc.be/SILSO/datafiles – downloaded 13 September 2025). **C** – yearly mean total sunspot number from 1700 to June 2024 (https://sidc.be/SILSO/datafiles – downloaded 13 September 2025). **D** – global mean temperature (12-month moving average) with 95% uncertainty shown. 30-year LOESS smooth also shown to indicate long-term trend. Anomalies are relative to the 1850–1900 average. Updated to July 2025. The present dip in temperatures reflects a transition from El Niño to ENSO-neutral conditions, with La Niña more likely than not later this year (Rohde *et al.*, 2025)

tions, Solar Influences Data Analysis Centre, July 1, 2025). We are not, therefore, currently receiving exceptionally high levels of solar irradiance, and so this cannot be an explanation for the exceptional warmth of 2023 to the present.

8. The "hockey-stick" curve of the global temperature rise, produced by Mann *et al*. (1998, 1999) and advocated by alarmists and IPCC, does not fit to other global or polar temperature change reconstructions based on multi-proxy data discussed above.

The so-called "hockey-stick" curve, which has become considerably more sharply delineated since the early studies of Mann and colleagues, represents well the distinctive course of climate warming over the past half-century: see extensive discussions in Summerhayes *et al*. (2024, 2025).

9. "It is sometimes argued that the Medieval Warm Period (MWP) followed by the Little Ice Age (LIA) were rather regional climatic changes. However, temperature reconstructions based on multi-proxy data from the whole Northern Hemisphere (Fig. 1B) published by Moberg *et al*. (2005) and further supported by tree-ring data provided by Schneider *et al*. (2015) indicate that the average surface-air temperature in the MWP was similar to that at the beginning of 21st century at least throughout the Northern Hemisphere".

These published researches, for the most part made by analysing marine or terrestrial plant remains, most likely represent not hemispheric annual averages but rather the spring and summer temperatures under which those plants grew (see Summerhayes *et al*., 2025, and references therein).

In detail, the Medieval Warm Period (MWP) was delayed by some 200 years in the Southern Hemisphere compared with the north, suggesting control by regional ocean variability (Neukom *et al*., 2014). Later studies by Neukom *et al*. (2019) demonstrated more generally the globally diachronous nature of the climate oscillations of the past 2000 years, and contrasted this pattern with the globally synchronous warming since the 20th century, which "provides strong evidence that anthropogenic global warming is not only unparalleled in terms of absolute temperatures, but also unprecedented in spatial consistency within the context of the past 2,000 years".

Over the past 2000 years, the Earth north of latitude 60°N has shown a gradual long-term trend of cooling, once short-term, low-amplitude events like the Medieval Warm Period and the Little Ice Age are excluded (Kauffman *et al*., 2009). But, from the end of the 19th century, this long-term trend reversed, with four of the five warmest decades of a 2000-year-long reconstruction occurring between 1950 and 2000 (Walsh, 2013). Twentieth century warming took temperatures above anything that their proxy data set revealed in the previous 19 centuries. The Arctic in the past 60 years has warmed by >2°C, about double the global average warming for the same period (Fig. 2), due to polar amplification driven by positive feedback from melting sea ice (Walsh, 2013).

Bjune *et al*. (2009) observed a similar pattern. From studies of pollen from lakes in Fennoscandia and on the Kola Peninsula, Russia, they found in 2009 that the mean July temperatures were about 0.2°C above present between 0 and 1100 CE and fell to about 0.2°C below present in the Little Ice Age. Abrupt warming occurred at about 1900 CE, and the 20th century was the warmest century since 1100 CE. They were unable to detect a Medieval Warm Period.

Ljungqvist *et al*. (2012) found that the warmth of the Northern Hemisphere in the 9th to 11th centuries was comparable to that of the 20th century mean. But the rate of warming from the 19th to the 20th century was by far the fastest between any two centuries in the past 1200 years, and was "unprecedented in the context of the last 1200 yr". They also noted that instrumental data showed that the last decade of the 20th century was much warmer than the 20th century mean nearly everywhere over Northern Hemisphere land areas, "thus providing evidence that the long-term, large-scale, Northern Hemisphere warming that began in the 17th century and accelerated in the 20th century has continued unabated" – and this was before the further, marked, warming of the last decade.

In eastern Canada, receding ice caps are exposing the remains of tundra plants, showing that 5000 years of regional summertime cooling has been reversed, taking the average summer temperatures of the past 100 years to levels higher than in any summer period for >44 kyr (Miller *et al*., 2013). That includes the peak warmth of the Early Holocene when Arctic summer insolation was 9% above modern levels. The north Canadian summers cooled by some 2.7°C over the past 5000 years, until the modern reversal. Their findings show that in the Arctic "anthropogenic emissions of greenhouse gases have now resulted in unprecedented recent summer warmth that is well outside the range of that attributable to natural climate variability" (Miller *et al*., 2013: p. 5750).

10. Sea level was higher earlier in the Holocene than today.

The recent study of Creel *et al*. (2024) does, as Dąbski notes, indicate that global mean sea level slightly exceeded early industrial levels after 7.5 ka BP, reaching 24 cm above present by 3.2 ka BP. This new evidence of modestly higher-than-now global sea level in the Holocene Thermal Maximum is indeed discordant with the recent IPCC report (2023). But the IPCC obtains its data solely from the best published information at the time of writing, and so its 2023 report would not have had access to the 2024 Creel *et al*. article. This does not mean, as Dąbski suggests, that the models used by the IPCC are wrong: they are simply calibrated with reference to available palaeoclimate data, and their next report will undoubtedly be adjusted to incorporate Creel et al.'s new data. For instance, compared with the Holocene global mean sea level (GMSL) reconstructions by Creel *et al*. (2024), Lin *et al*. (2025) estimate substantially lower GMSL during the Early to Middle Holocene.

Dąbski does not refer to the other conclusions of Creel *et al*. (2024): that the rate of sea level rise between 1850 and 2005 (~1.5 cm/yr) was likely higher than any in the last 4000 years (though likely not than any in the last 7000 years, when glacial-phase ice was still melting); and that future sea level rise, under any emissions scenario, will more likely than not exceed the maximum Holocene level by 2060. It is already well on the way to this: over the last decade sea level rise has averaged 4.5 mm/yr, and in 2024 this increased to 5.9 mm/yr according to NASA data (NASA, 2025b). There is an inherent lag between temperature rise and resultant sea level rise, so we are not yet seeing the full sea level effects of the global temperature rise since the mid-1970s.

11. Polar ice melt: Dąbski suggested: i) there had been a significant slowdown of Greenland ice melt since 2013, ii) the negative trend for Antarctic ice sheet mass turned to positive a couple of years ago; and iii) there had been a still-stand in Arctic summer (September) sea ice cover since 2008.

We will address Dąbski's points by the same numbers.

i) Analysis of Greenland ice sheet loss by Poinar *et al*. (2024), as part of NOAA's Arctic Report Card, shows that the ice sheet has experienced net annual mass loss for 27 years, in every year since 1998. The rate of loss since 2013 was slightly less than it was in 1998–2013. Nevertheless, the mean discharge of solid ice in 2024 exceeded the mean for the 1991–2020 period. Indeed, the above-average discharge in 2024 continued the ongoing high discharge rate period that began in 2005 and peaked over 2020–2021 (Poinar *et al*., 2024).

ii) In Antarctica, Otosaka *et al*. (2023) reported that ice losses continue to be dominated by mass loss from West Antarctica (82 ±9 Gt/yr) and, to a lesser extent, from the Antarctic Peninsula (13 ±5 Gt/yr), while East Antarctica remained close to a state of balance, with a small gain of 3 ±15 Gt/yr, but was the most uncertain component of Antarctica's mass balance. These patterns continue the Antarctic ice loss trends observed since 1992, contrary to Dąbski's claim.

iii) The analysis of Arctic sea ice extents for September clearly does show steadily decreasing trends from 1979 to 2005, with no statistically significant decline in September since 2005. Large ensemble simulations suggest that this 'pause', which applies throughout the year, is due to natural internal variability in the Arctic climate system (England *et al*., 2025), possibly related to oceanic conditions linked to the North Atlantic Oscillation (Yeager *et al*., 2015).

As regards Antarctic sea ice, extreme lows in summer sea ice cover occurred in 2016–2017, 2022 and 2023 (Doddridge *et al*., 2025), warming the coastal Southern Ocean and affecting its ability to take up heat and carbon (Silvano *et al*., 2025). The association of declining sea ice cover (Doddridge *et al*., 2025) with increasing land ice loss from West Antarctica and the Antarctic Peninsula (Otosaka *et al*., 2023), suggests that Antarctic sea ice has begun a long-term shift towards persistently low coverage like that seen in the Arctic since 1978. The decline in summer Antarctic sea ice is likely related to the recent warming of the Southern Ocean (mentioned earlier), and will likely have contributed warm moist air to the continent, thus accounting for the slight recent slowing of continental ice loss. Recent studies warn of the potential for substantial irreversible ice loss and consequent sea level rise with little or no further climate warming (e.g., Chandler *et al*., 2025).

12. Climate Catastrophe? And "We are less vulnerable now to climatic hazards".

Dąbski claims that messages on the World Meteorological Organization website about spiralling weather and climate impacts are poorly supported by the data. However, Gebrechorkos *et al*. (2025) demonstrate that over the period 1901–2022 global drought severity has increased by 40%. Not only are dry regions becoming drier, but so are wet areas. During 2018–2022, the areas in drought expanded by 74% compared with 1981–2017. The trend is driven by atmospheric evaporative demand, and so will likely increase with further warming.

Similarly, Martinez-Villalobos *et al*. (2025) found that as global temperatures have risen, heatwaves are not only becoming hotter but that their duration is increasing faster than the rate of temperature rise, i.e. showing a non-linear, accelerating, increase. Another measure of rising climate risk is financial, as shown by the increasing reluctance of insurance companies to provide cover for areas most severely affected by climate change (Hemmati *et al*., 2025). The reports of the WMO, unlike the 'catastrophe' description given them by Dąbski, seem balanced and prudent in this respect.

DISCUSSION AND CONCLUSIONS

The science behind climate change is no different from any other kind of science, such as that which allows physicists to explore the nature of outer space, biologists to probe the inner workings of the cell, and chemists to analyse the properties of the chemical elements such as silicon. Practical results of these studies include the space industry, modern medicine and the computer on which this response was written. And climate scientists, like other scientists, are linked to colleagues across the world. They work as a community to produce data and analyse them, and robustly vet claims made using these data by peer-reviewing manuscripts and through specialist conferences and workshops. The critical interrogation of results is central to the process, and published work is continually evaluated. Syntheses, such as those by the IPCC, are crucially important too. Consequently, climate science has had a successful track record in explaining and projecting under different emissions scenarios the likely course of future climate change (IPCC, 2023; Summerhayes, 2025).

Nevertheless, contemporary climate science attracts particular controversy and attack because its findings unequivocally identify the burning of fossil fuels as the key factor underlying contemporary, observed, global warming. Fossil fuel powers all our lives and makes up the largest and most profitable industry in the world (and, specifically, has been closely interwoven with the development, operation and funding of geology, virtually from its beginnings as an organized science). More widely, hydrocarbon-based energy has underpinned much of the post-war growth in prosperity and helped pull billions of people out of poverty. As the historian Dipesh Chakrabarty (2009) has put it: "The mansion of our modern freedoms is built on the ever-expanding use of fossil fuels".

This dilemma has prompted the questioning of the link between fossil fuel burning and climate change, a questioning amplified by the spread of much misinformation about climate science, in part directly funded by the hydrocarbon industries. This is akin to the denials from tobacco companies that cigarette smoking caused cancer (Oreskes, Conway, 2010a, b) – even when these hydrocarbons companies long knew from their own data that greenhouse gas emissions would lead to global warming (Supran, Oreskes, 2017). This misinformation has reached into the heart of national executives, as for instance in the 2025 US Department of Energy (DOE) report (Christy *et al*., 2025) that makes similar claims to those advanced by Dąbski that we respond to here.

Such widespread misrepresentation of climate science is not clearly obvious to the general public (Bardon, 2019) – and the technically detailed 453-page point-by-point rebuttal of the DOE report by 86 climate scientists (Dessler, Kopp, 2025) is unlikely to circulate and be read widely in public circles. It is difficult overall for society to access the latest climate science – a genuinely complex topic – much of the detail of which is published in scientific journals and often hidden behind publishers' paywalls. As a result, the easiest way for the public to seek information about climate change is through the internet. Information there is usually not peer-reviewed, and often is misinformation (unintentionally incorrect or misleading) and/or disinformation (deceptive and a form of propaganda). This is a new problem, as the internet did not reach most homes until the mid-2000s. Furthermore, global warming denial has become fashionable among influencers, with 8 out of 10 on-line shows spreading climate misinformation (Yale Climate Connections, 2025). Finally, many major media outlets are owned by wealthy individuals, often sympathetic to the fossil fuel industries, and commonly promote denials of, or downplay, global warming. A new report from the International Panel on the Information Environment (IPIE, 2025) found that climate denialism has evolved into campaigns focussed on discrediting solutions to the global warming problem, with political leaders, civil servants and regulatory agencies being targeted in order to delay climate action.

To explain the mainstream science of climate change, books and articles are written for a general audience about global warming and sea level rise (e.g., Zalasiewicz, Williams, 2012; Alley, 2013; Bender, 2013; Ruddiman, 2014; Summerhayes, 2020, 2023; Hay, 2021). These describe and explain the science behind the overwhelming scientific consensus (that greenhouse gas rises have become dominant drivers of climate change). Challenges to the scientific consensus from within the scientific community are addressed in detail, as we do here in response to the article by Dąbski (see also Summerhayes *et al.*, 2025, in response to Marks, 2025).

We have examined the key points in Dąbski's article that question this consensus and find that they do not stand up to scrutiny. Thus:

- while a few scientists do deny the role of greenhouse gases, there are far more (and far more qualified ones) who accept it (e.g., Dessler, Kopp, 2025);
- climate sensitivity is debated – but even if the conservative estimate of the IPCC (~3°C for a doubling of atmospheric CO_2) is correct, it nevertheless has serious climate consequences;
- there is solid evidence that the climate change of the past half-century has no precedent in the last two millennia;
- the role of CO_2 in climate change has been demonstrated beyond reasonable doubt;
- in at least the last 0.8 Ma of Pleistocene warmings, CO_2 and temperature rose and fell in close correspondence;
- climate models used by the IPCC substantially agree with observational data;
- solar irradiance variations cannot explain post-industrial temperature rise;
- the current 11-year solar cycle (its peak now terminating) is not the greatest ever recorded, rather being of modest scale;
- we are not less vulnerable to climate hazards now;
- the current global CO_2 rise and warming has no known precedent in magnitude and dynamics within the Holocene;
- the 'hockey stick' curve of Mann fits, increasingly well, observational data;
- Holocene climate fluctuations such as the Medieval Warm Period and Little Ice Age varied through time and space, contrasting with modern globally synchronous warming;
- sea level was indeed slightly higher early in the Holocene than at its pre-industrial level, but is set to exceed that level over coming decades (sea level lags global warming because it is tied to land ice melt);
- there has been no overall slowdown of polar ice melt (apart from the recent flattening of sea ice loss in the Arctic);
- the reports of the World Meteorological Organisation are not 'alarmist' representations of 'catastrophe', but balanced responses to the severity of ongoing climate phenomena.

The scientific consensus on contemporary global warming that Dąbski questions, therefore, is still very much in place. This is not an 'alarmist' position, to use his phrasing, but simply recognition of a major and consequential change to the Earth System.

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