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Global Temperature Change by Solar Variation Outweighed Since 1940s by Warming Effect of Anthropogenic Airborne Black Carbon, not CO_2?

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Abstract

Solar control of global warming and cooling (Svensmark Theory) is supported by the similarity of two published graphs: (1) average near-surface air-temperature for the last 9,000 years (from proxies and, since 1880, NASA thermometer charts); and (2) solar-magnetic output (proxies). Graph-to-graph visual cross-matching of spikes (peaks, troughs) and of multi-century trends reveals a variable temperature lag (~100-225 years). Despite the good qualitative match, the correlation coefficient for the last 2,000 years is low (0.3), attributable to lag variability and numerous non-matching spikes. Relative amplitudes of cross-matched peaks indicate disproportionate warmth since 1940, coinciding with the large growth in coal- and oil combustion since World War Two. Based on two features of NASA's temperature charts, the main cause of this excess warmth is not carbon dioxide (CO_2): (1) after 1980, warming paused (4-8 years) four times, conflicting with CO_2's non-pausing growth; and (2) since 1985, warming is faster above land than ocean, at odds with CO_2's spatial homogeneity, instead implicating poorly dispersed airborne black carbon (essentially soot, which absorbs solar radiation, thereby warming the air), hitherto widely considered the second most important human-produced warming agent. Soot is emitted by the burning of coal, diesel-oil, and wood, *mainly on land*. Incriminating especially coal: (1) the mentioned land/ocean decoupling began (1985) only 10 years after the growth-rate of world annual coal-consumption abruptly tripled; and (2) the longest warming-pause (2003-2011) started soon (15 years) after the first-ever coal-growth pause (1988-1999) began. Consistent with this evidence that CO_2 has, in reality, relatively little warming effect, numerous authors have reported that changes in CO_2 *follow* changes in temperature. Apparently, therefore, CO_2's greenhouse effect is largely (entirely?) outweighed by little-known feedbacks. Indeed, the Intergovernmental Panel on Climate Change acknowledges cloud-related feedbacks as climate models' largest uncertainty. Thus, stopping anthropogenic warming might be tantalisingly easy: simply stabilise coal- and oil combustion, thereby ending airborne-soot *growth*. Natural gas (almost soot-free) could be substituted for coal in electricity generation. Gas reserves are sufficient for decades, perhaps long enough for development of nuclear fusion (soot- and CO_2-free).

Keywords: climate; warming; Sun; soot; CO_2.

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1. Introduction

Climate scientists seldom look back beyond the establishment of a reliable global thermometer network, in the 19th Century. A longer perspective is provided in this contribution, using published proxy-temperature- and proxy-solar-output data going back ~9,000 years, revealing that, until very recently (20th Century), solar-magnetic fluctuations appear to have governed Earth's average temperature (Section 4.1). By integrating these diverse data spanning thousands of years and fusing them with meteorological and industrial (coal- and oil-consumption) data that span the last few decades and centuries, a better understanding is gained of: (a) the extent to which today's climate is overwarm; (b) the year or decade in which the extra warming began; and (c) the cause.

2. Previous studies on the importance of the Sun and of black carbon

Previous authors have invoked a correlation between solar activity and climate variations, for various Holocene time-intervals, using diverse temperature proxies, e.g., Bond et al. (2001), Jiang et al. (2005, 2015), Usoskin et al. (2005), Perry (2007), Eichler et al. (2009), Stefani (2021), Harde (2022), Connolly et al. (2023), Scafetta (2023). The cited studies found temperature lag-times ranging from nil (undetected) to ~100 years. According to Perry (2007, p. 353), "A progression of increasing lag times can be spatially linked to the ocean conveyor belt, which may transport the solar signal over a time span of several decades. The lag times for any one region vary slightly and may be linked to the fluctuations in the velocity of the ocean conveyor belt". In another study, simulated Atlantic sea-level fluctuations for the last 1,500 years match solar variations, with a lag of ~125 years (van de Plassche et al., 2003). According to Jiang et al. (2005, p. 73), "The Little Ice Age has a well-documented correlation with the Spörer and Maunder solar minima, which may have been partly or even entirely linked to changes in solar irradiance (Lean, 2002)."

The contribution of black carbon (essentially soot) to atmospheric warming is highly uncertain (italics below added for emphasis). Bond et al. (2013, p. 5388) stated: "The best *estimate* of industrial-era climate forcing of black carbon ... is +1.1 W m^{-2} with 90% *uncertainty bounds* of +0.17 to +2.1 W m^{-2} [i.e., *very wide uncertainty range*; see also their table 1 and figure 35] ... We *estimate* that black carbon ... is the second most important human emission in terms of its climate forcing", after CO_2. Black carbon's warming effect was *estimated* to be 70% as strong as CO_2 (p. 5497). Intergovernmental Panel on Climate Change (IPCC) *estimates* are only ~35% and 20%, again with *large uncertainties* (IPCC, 2013a, figure SPM.5; IPCC, 2021a, figure SPM.2c). Ramanathan and Carmichael (2008, p. 221) said: "Black carbon in soot is the dominant absorber of visible solar radiation in the atmosphere. ... emissions of black carbon are the second strongest contribution to current global warming ... In the Himalayan region, solar heating from black carbon at high elevations may be just as important as carbon dioxide in the melting of snowpacks and glaciers." Airborne soot was likewise credited with major climatic importance by Allen et al. (2012), who attributed recent northward expansion of the tropical belt to laterally heterogeneous atmospheric warming by soot (and ozone). "Owing to increased combustion of fossil fuels and biofuels, black carbon aerosols ("An aerosol is a suspension of fine solid particles or liquid droplets in air or another gas" [Wikipedia, 2026a]) have increased substantially over much of the Northern Hemisphere during the last few decades, particularly over southeast Asia ... black carbon has increased monotonically since 1970 on average in the low and midlatitudes, including the band 30°-50° N ... where recent studies show that heating can displace the tropical edge" (Allen et al., 2012, p. 350-351) ... "Our analysis strongly suggests that recent Northern Hemisphere tropical expansion is driven mainly by black carbon and tropospheric ozone" (p. 352). In a follow-up article (co-authored by Allen), Zhao et al. (2020, p. 1) added: "Our results show that ... black carbon (BC) aerosol drives tropical expansion ... BC, especially from Asia, is more efficient ... than greenhouse gases in driving tropical expansion ... Although a formal attribution is difficult, scaling the normalized expansion rates to the historical time period suggests that BC is the largest driver of the Northern Hemisphere tropical widening but with relatively large uncertainty. ... BC warms the troposphere, particularly in the NH midlatitudes where most emissions occur".

3. Materials and methods

This contribution is based solely on the analysis, interpretation and synthesis of published information. No new data are presented, only ideas and interpretations resulting from an unfunded (hence impartial) exhaustive survey of the literature in diverse relevant fields, including geology, archaeology, climatology, paleoclimatology, meteorology, oceanography, astrophysics, and polar glaciology. The study has lasted eleven years so far (since 2015), leading to this article on soot and to three other papers on sea level (Higgs, 2026a, b, c). Microsoft (2022) Excel was used for plotting graphs (Figures 1 to 12) from published raw data (except a few charts obtained directly from the NASA [2025] website) and for calculating Pearson correlation coefficients.

4. Analysis and results

4.1 Global Temperature Largely Solar-Controlled Prior to 1940

Published graphs of solar-magnetic output (Wu et al., 2018) and global near-surface air temperature (Marcott et al., 2013), both based on proxies (largely geological) spanning the last 9,000 years (Early to Late Holocene interglacial period), are visually alike, showing similar overall form and several cross-matching multi-century trends (rising, falling; Figure 1). However, the temperature graph (Figure 1B) is heavily smoothed, due to averaging of 73 globally distributed datasets

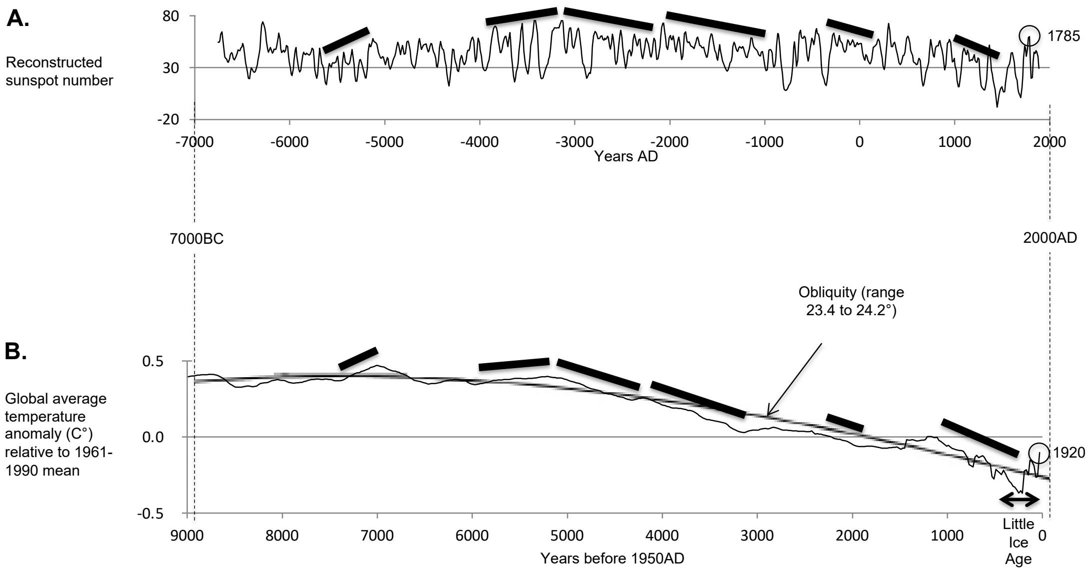

Figure 1: Visual correlation for the last 9,000 years between: (A) reconstructed sunspot number, a solar-magnetic-output proxy, based on ice-core ^{10}Be, 10-year time-steps, data of Wu et al. (2018); and (B) global average near-surface temperature anomaly relative to 1961-90 mean, based on multiple proxies, sampling resolution 20-500 years, 20-year time-steps, data of Marcott et al. (2013). In A and B, multi-century trends (rising, falling; black bars) match quite well. The overall shape of the two graphs is even more similar after tilting the temperature graph leftward to compensate for long-term cooling by Earth's declining axial obliquity (curved grey line, from Cionco et al. [2020]). Marcott's final temperature value, for 1940, 0.7C° warmer than 1920, is omitted here, as he doubted its accuracy (see also Vinos [2017]).

(diverse palaeotemperature proxies) and 1,000 Monte Carlo runs (Marcott et al., 2013). This smoothing suppresses short-term variability, rendering the graph less spiky (but note unpublished spikier reprocessed version of Vinos [2017]), hampering correlation (Figure 1). This disadvantage is overcome here (Figure 2) by substituting a Greenland temperature graph (Vinther et al., 2009), one of the 73 datasets incorporated in the Marcott et al. (2013) global compilation. The Greenland graph has the same general shape as the global graph (Figure 1B versus 2B; i.e., the Greenland dataset is a reasonable world-proxy), but is much spikier because the graph is the average of just two ice-core-isotope profiles, which are nearly identical, i.e., smoothing is minimal. Figure 2 reveals a relatively good qualitative correlation between solar output and Greenland temperature, with numerous prominent spikes (peaks, troughs) and multi-century trends that can be visually cross-matched with reasonable confidence. Spikes in temperature appear to lag by a variable amount, ~100 to 225 years, behind corresponding solar spikes (Figure 2). This wide range of lag-times possibly reflects: (a) ocean conveyor-belt circulation (Rahmstorf, 2006) changes in velocity (Section 2); and/or (b) dating errors (counting of ice-core laminae), which inevitably increase with age. The longest lag (225 years) is between the exceptionally long solar grand-minimum of ~ 6505-6365 BC (Inceoglu et al., 2015) and the globally cold "8.2-kiloyear event" that spanned ~ 6250-6130 BC in Greenland (Figure 2B and cited dataset), popularly attributed instead to hypothetical sudden emptying of an ice-dammed lake (Wikipedia, 2026b). Near the other (young) end of the graphs, the Little Ice Age signature-cluster of three cold spikes is offset ~150 years from a trio of solar minima (Figure 2; note that the middle spike of each triplet is the lowest value of the entire 9,000 years).

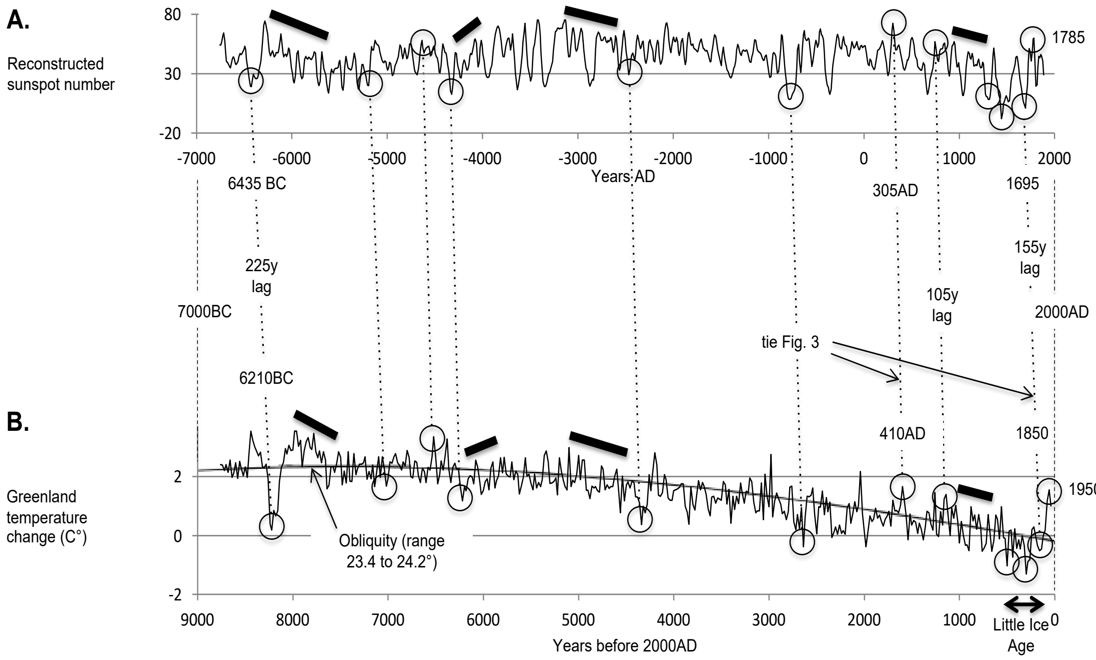

Figure 2. Visual correlation for the last 9,000 years between: (A) reconstructed sunspot number, a solar-magnetic-output proxy (same data-source as Figure 1A); and (B) Greenland near-surface air temperature change based on proxy ice-core ^{18}O (averaged Agassiz and Renland ice cores), sample resolution 20 years, data of Vinther et al. (2009). Several prominent peaks and troughs (circled) and multi-century trends (black bars) match quite well. As in Figure 1, the similarity in overall shape of the graphs is clearer after tilting the temperature graph leftward (curved grey line from Cionco et al. [2020]). Slant of dashed correlation-lines indicates a lag of 100-225 years between solar changes and corresponding temperature changes.

The time-lag is possibly due to ocean thermal inertia (i.e., the ocean's vastness, high specific heat and slow mixing render it slow to reach [transient] equilibrium), in agreement with Wigley (2005, p. 1766) who, summarising the results of his own and others' modelling, said: "Oceanic thermal inertia causes climate change to lag behind any changes in external forcing ... many decades". Supporting this evidence that solar-driven temperature fluctuations originate in the ocean rather than on land, Humlum et al. (2013) showed that changes in sea-surface temperature (SST; generally a good surrogate for near-surface marine air temperature [Cayan, 1980; Rubino et al., 2020, their figure 4]) precede changes in land-surface-air temperature (LSAT), by ~2 months, i.e., warming (or cooling) begins at the ocean surface, then migrates onto land. This migration self-evidently can only occur in regions where the ocean-surface is warmer than the adjoining land (cf. Wikipedia, 2026c). Noteworthy in this regard: (a) due to the ocean's large thermal capacity, the rate and amount of temperature change during any warming (or cooling) event are higher for land than for ocean (Humlum et al., 2013, their figure 5); and (b) *globally averaged* LSAT exceeds SST and the difference is growing with time (Section 4.2). Supporting the confirmation by Humlum et al. (2013) that the ocean warms the atmosphere, not vice versa, the annual average SST in most of the northern Pacific and northern Atlantic is slightly (0-1C°) warmer than the air immediately above (Cayan, 1980, his figure 3a). These observations contradict the reverse assumption, by many climate scientists, that temperature changes originate in the atmosphere and are transmitted to the ocean, e.g., "the ocean soaks up heat trapped in the atmosphere by carbon dioxide and other greenhouse gases" (WHOI, 2025).

The fair qualitative correspondence between the temperature- and (time-lagged) solar graphs (Figure 2) supports Svensmark's (2007) theory that increased solar-magnetic output deflects more galactic cosmic rays, reducing cloud cover, allowing increased warming by the Sun because "Cloud tops have a high albedo and exert their cooling effect by scattering back into the cosmos much of the sunlight that could otherwise warm the surface" (Svensmark, 2007, p. 1.20). Early on, Svensmark and Friis-Christensen (1997) and Svensmark (1998) could not distinguish which cloud level (low, medium, high) was most affected. However, by 2000, it was evident that low clouds (i.e., those below ~3 km) are much more affected than the others (Marsh and Svensmark, 2000; Pallé and Butler, 2000). According to Pallé and Butler (2000, p. 4.22), "our results imply that, possibly excluding the last decade or so when an accentuated rise in global temperatures is widely accepted to have occurred as a result of the enhanced greenhouse effect, most of the global warming of the 20th century can be quantitatively explained by the combined direct (irradiance) and indirect (cosmic-ray induced low cloud) effects of solar activity." It is important to note that Marsh and Svensmark (2000), Pallé and Butler (2000) and Svensmark (2007) all used the same 1983-1994 cloud data-set, which begins only 2 years before the 1985-onward divergence of land- and ocean warming, attributed here to airborne soot (Section 5.1).

Rejecting Svensmark's theory, the IPCC rather subjectively stated: "Although some studies found statistically significant correlations between the cosmic ray flux and cloudiness at the regional scale ... these correlations were generally weak, cloud changes were small" (IPCC, 2013b, p. 613). A companion IPCC chapter added: "The lack of trend in cosmic ray intensity over the 1960–2005 period (McCracken and Beer, 2007) provides another argument against the hypothesis of a major contribution of cosmic ray variations to the observed warming over that period" (IPCC, 2013c, p. 886). However, this statement unfortunately neglects the oceanic time-lag discussed above.

Having thus dismissed Svensmark, the IPCC (2014, 2021a) estimated that the Sun's effect on climate change is very small, via fluctuations in the *total solar irradiance* (TSI), which are likewise very small, as opposed to the *magnetic-flux* variations invoked by Svensmark, which occur in lockstep with TSI but are much larger, e.g., see Benevolenskaya and Kostuchenko (2013, their figure 1). For example, the solar-magnetic flux *doubled* from 1901 to 1992 (Lockwood et al., 1999; note, in their figure 3, peak flux in 1992, corresponding to the 1992 cosmic-ray strong minimum [Oulu, 2025]), arguably to its highest level in >9,000 years (Solanki et al., 2004).

Non-matching spikes are also numerous (Figure 2). Temperature spikes with no obvious solar counterpart include: cold spikes, some possibly attributable to terrestrial volcanic mega-eruptions (cf. Sigl et al., 2015; Büntgen et al., 2016); and warm spikes, perhaps due to surges in submarine volcanism (i.e., lava eruptions and/or hydrothermal venting; cf. "plate climatology" [Kamis and Kamis, 2016]), a hidden, unmeasurable, potentially major contributor to climate change. On the other hand, the converse situation, examples of solar spikes lacking temperature expression, might reflect submarine-heat surges or lulls counteracting the solar influence. The many non-matching solar and temperature spikes result in a relatively low, though positive, correlation coefficient of 0.30 for the last 2,000 years of Figure 1 (calculated using the data-sources cited in the caption and equalising the data-spacing to 20 years by stripping every second value from the solar dataset). This calculation neglects the temperature lag (see above), whose non-constancy (variability) prevents the determination of a more appropriate (time-lagged) correlation coefficient.

Spectral analysis provides further support for the Sun's role in climate change. Analysing a 1-2000AD global temperature-proxy curve compiled from published studies, Lüdecke and Weiss (2017) discovered a strong ~190-year cycle, matching the DeVries/Suess solar cycle. More persuasively, a spectral analysis of the 1850-2017 sunspot series and the Hadley-CRU global-average temperature data-set (Section 4.2) found temperature cycles "that can reasonably be assigned to solar variability for most and even possibly all of them" (Le Mouël et al., 2020, p. 24).

Focusing on the last two millennia (Figures 3 and 4), the same solar graph (Wu et al., 2018) closely tracks the authoritative PAGES2k (2019) global multi-proxy temperature reconstruction. Cross-matched trends and spikes again reveal a variable temperature delay (~130-165 years, Figure 3), e.g., the Little Ice Age (~1440-1920AD) corresponds to the triple Wolf-Spörer-Maunder solar-minima cluster (~1270-1760).

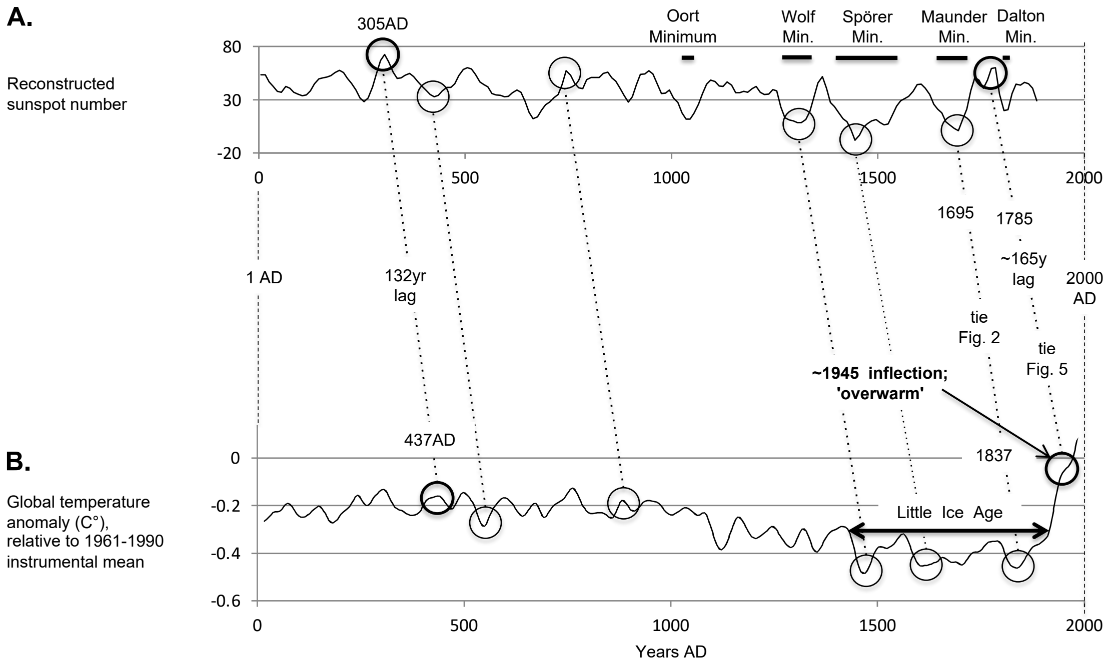

*Figure 3. Visual correlation, for the last 2,000 years, between: (A) reconstructed sunspot number, a solar-magnetic-output proxy (same data-source as Figure 1A); and (B) global mean temperature, 1-year time-steps, 31-year smoothing, based on multiple proxies (tree rings, etc.), data of PAGES2k (2019; median of all their reconstruction methods). Five solar minima from Steinhilber and Beer (2011). Several prominent peaks and troughs (circled) correspond well; slant of correlation lines indicates ~150-year lag, attributable to ocean thermal inertia (see text). The four **bold** circles demonstrate 1945AD disproportionate warmth, i.e., 437AD was cooler than 1945, despite higher corresponding solar activity (305 AD) and higher obliquity (cf. Figure 1B curved black line).*

4.2 Solar Control of Global Temperature Increasingly Outweighed After 1940

Remarkably, graph-to-graph proportionality of peaks and troughs becomes disrupted in the 20th Century. Post-1940 global warmth is disproportionately high, to an extent that increases with time, relative to the corresponding level of solar output (visually calibrated to previous episodes; Figures 3, 4, 5). To elucidate the excess warmth, Figure 5 compares the *thermometer-measured* 1880-2024 global average annual near-surface air temperature of NASA (2025) (NB this dataset is almost identical to that of Hadley-CRU [Met Office, 2025]) versus annually resolved solar modulation, a measure of solar-magnetic shielding of Earth from cosmic rays (Brehm et al., 2021). In Figure 5, global temperatures before 1940 closely mimic solar output, after subtracting a ~160-year lag, e.g., the three main temperature spikes (1898 warm, 1909 cold, 1942 warm) match three solar spikes (1740 high, 1751 low, 1784 high), moreover with constant proportionality. In contrast, post-1940 warming is excessive, manifested in three ways:

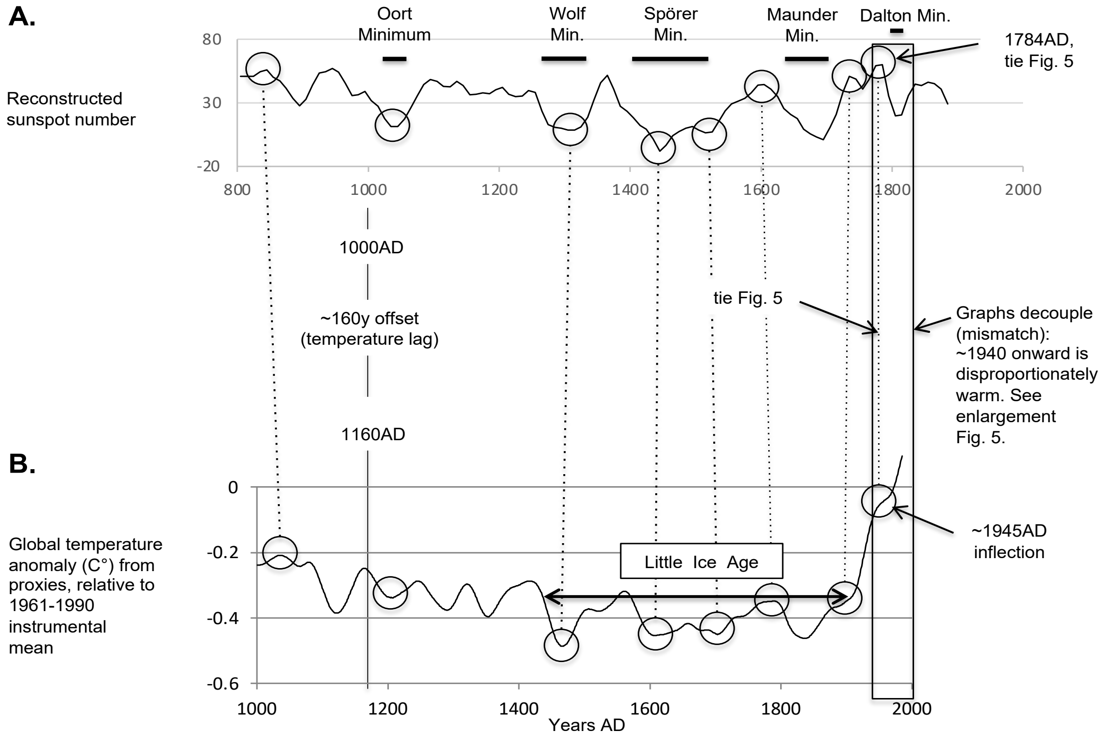

Figure 4. Time-shifted visual correlation, for the last 1,000 years, between: (A) reconstructed sunspot number, a solar-magnetic-output proxy; and (B) global mean temperature from proxies. Same data-sources as Figure 3. The best visual alignment of spikes (peaks, troughs; circled) is obtained by applying ~160-year temperature lag.

1. 1942-56 cooling was overly weak for its corresponding solar decline (~160 years earlier), by comparison with previous similar declines (Figure 5, compare Box I and dashed box);
2. therefore, the ensuing 1957-1975 interval of near-constant temperature (Box II), equating to the Sun's ~1800-1820 Dalton Minimum, was warmer than earlier times of *greater* corresponding solar strength (compare Box II and dashed box; see also Figure 3);
3. 1994 to 2024 overall strong warming (despite the controversial 'Global Warming Hiatus', said to span 1998-2013 [Wikipedia, 2026d] but in fact only 2003-2011 [Figure 5B smoothed curve; Section 5.1]), anomalously equates to 1835-1865 net solar *decline* (comprising a dip and a rise; Box III). This 1994-2024 warming is verified by: satellite (Spencer, 2025); balloon-radiosonde (Christy et al., 2018); and Arctic sea-ice retreat (Stroeve et al., 2007; Mahoney et al., 2008; Connolly et al., 2017; Bliss et al., 2025). The disproportionate warming since 1994 relative to the corresponding lagged solar output applies to the world as a whole (Figure 5) and to land and ocean individually (Figure 6).

Tellingly, 1940 to 2024 warming amounted to a substantial 1.1C°, and SST 0.8C°, despite a net *decline* in corresponding overall solar output (Figures 5 and 6). These observations point to dominance of a non-solar warming agent.

5. Discussion

5.1. Human Cause of Post-1940 Excess Warmth

Incriminating humankind, the 1940 onset of excess warmth (Section 4.2) coincides with World War Two and its huge demand for coal (for producing electricity, steel and cement) and oil (propulsion of aircraft, ships, vehicles). For example, the growth-rate of world annual oil consumption doubled in 1940 (OWD, 2025a). Post-war reconstruction, industrial expansion, and massive population growth (1950, 2.5 billion; 2020, 8 billion) have further increased demand for oil and coal.

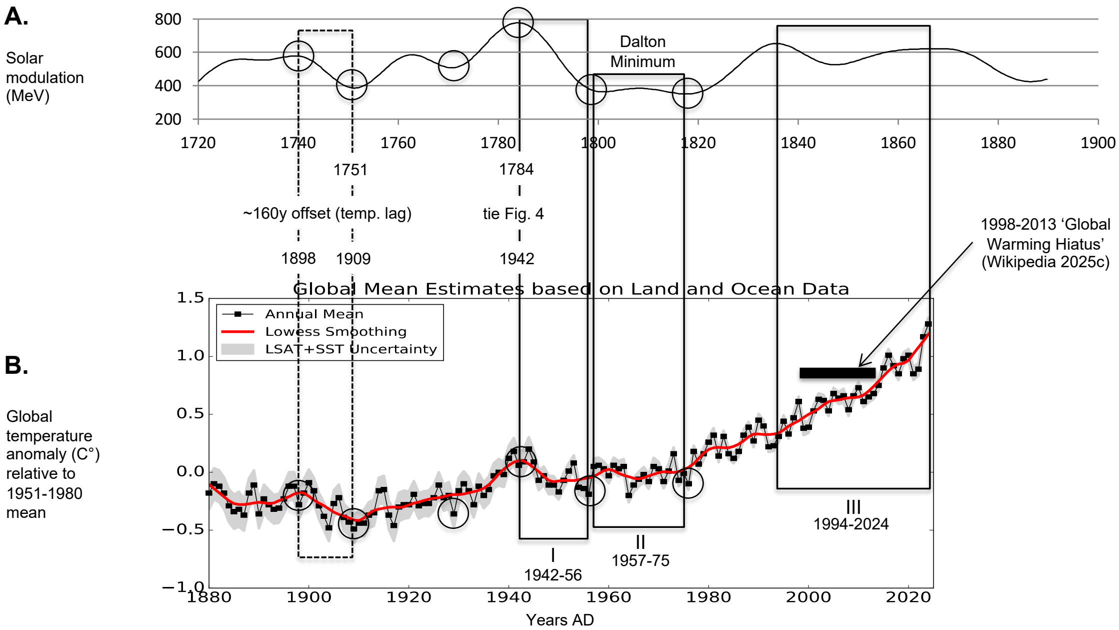

Figure 5. Visual correlation between: (A) 1720-1890 solar-magnetic-output proxy, 20-year-smoothed annual tree-ring C14 data of Brehm et al. (2021); and (B) 1880-2024 annual global average temperature anomaly, i.e., averaged land-surface-air temperature (LSAT) and sea-surface temperature (SST) (NASA, 2025). Five-year-smoothed curve in red. Graphs are offset ~160 years in accordance with Figures 2, 3 and 4. Black boxes I-III highlight three manifestations of post-1940 excess temperature (relative to corresponding solar output); these and the dashed box are described in the text.

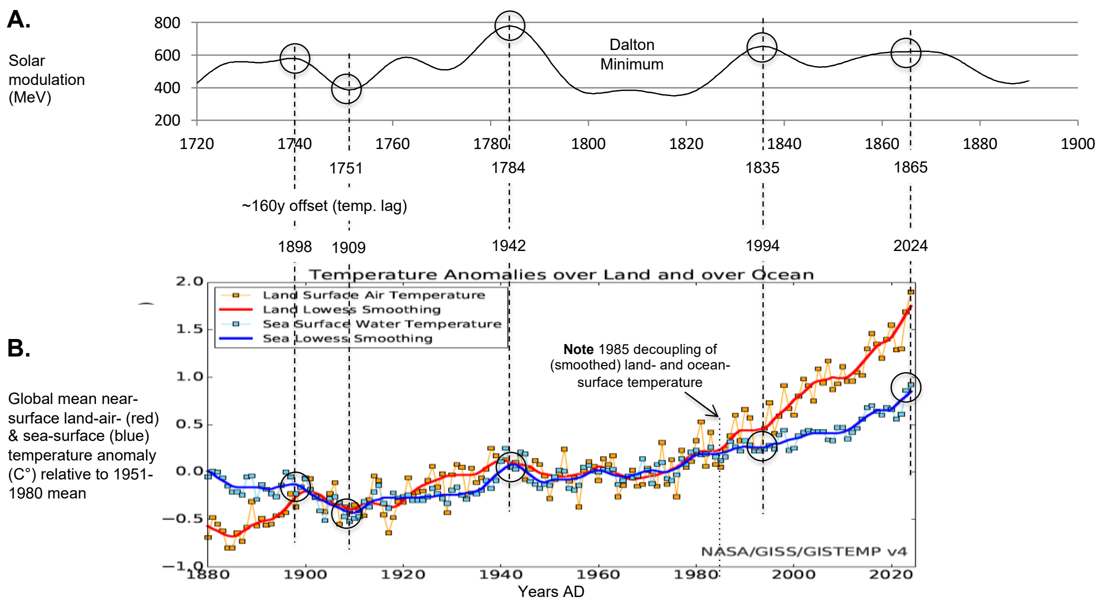

Figure 6. Visual correlation between: (A) 1720-1890 solar-magnetic-output proxy, 20-year-smoothed annual tree-ring C14 data of Brehm et al. (2021; and (B) 1880-2024 average annual world land-surface air temperature (LSAT, red) and sea-surface temperature (SST, blue) (NASA, 2025). In B, the thin zigzag lines connect annual values; thicker wiggly red and blue lines are 5-year-smoothed values. Graphs are offset ~160 years in accordance with Figures 2, 3 and 4. The ten circles illustrate that, until 1940, SST was proportional to the corresponding (time-lagged) solar output, but was disproportionally high thereafter.

Recognition of human culpability would implicate one or both of the generally agreed main agents of anthropogenic global warming, namely: (a) rising carbon dioxide (CO_2) emissions (from combustion of oil, gas, coal and wood), the overriding factor according to the IPCC (2014, 2021a, b) and to the great majority of climate scientists; and (b) airborne particulate black-carbon aerosol (Bond et al., 2013; Higgs, 2022, 2023). Black carbon is produced mainly by combustion of diesel-oil, coal and wood (Bond et al., 2013, table 8). In their landmark review of soot's estimated climatic effects, Bond et al. (2013, p. 5381) considered black carbon to be "the second most important human emission in terms of its climate forcing in the present-day atmosphere; only carbon dioxide is estimated to have a greater forcing." Black carbon is doubly problematic, causing warming in two ways: (1) *airborne* soot warms the atmosphere; and (2) *deposited* soot reduces snow- and ice albedo. Both airborne and settled soot are constantly replenished by combustion of wood (natural wildfires and human fires for cooking, heating) and of fossil fuels. In a Greenland ice core, the decadal mean concentration of black carbon is no higher for 1970-2010 than for 1750-1880 (Goto-Azuma et al., 2024, their figure 4), suggesting that by far the main contribution since 1970 is from boreal forest fires. Higher values in the intervening period reflect industrial contributions, mostly from North America (Goto-Azuma et al., 2024). Soot settling on ice and snow is estimated to have only ~20% of the warming effect of airborne soot (Bond et al., 2013, table 1 and figure 35).

Further inculpating humans, *and suggesting that airborne soot has a greater warming effect than CO_2*, published meteorological evidence indicates that warming is both laterally (geographically) and vertically inhomogeneous. This evidence includes:

1. lack of Antarctic warming since 1980 or earlier (Figure 7) (Doran et al., 2002), i.e., so-called global warming is not truly global;
2. since 1985, faster near-surface warming over land than over the oceans, in contrast to pre-1985 near-lockstep warming and cooling (Figure 8C);
3. faster warming since 1985 in the northern hemisphere (NH; land-ocean average) versus southern (SH) (Figure 9C);
4. faster warming of the lower atmosphere (~0-9 km average, satellite-measured [UAH 2025]) above land than over the ocean (Figure 8A, B) (Klotzbach et al., 2009, table 1);
5. likewise the NH versus SH (Figure 9A, B);
6. near-surface warming faster than lower-atmosphere warming, both above land (Figure 8A, C) and over the NH (Figure 9A, C); and
7. near-surface warming at approximately the same rate as the lower atmosphere over oceans (Figure 8B, C; Klotzbach et al., 2009, table 1) and over the SH (Figure 9B, C). This observation verifies that surface (thermometer) and satellite measurements are well calibrated, as does their dual determination of non-warming in Antarctica (Figure 7).

The strong lateral and vertical warming gradients (observations 1 to 7 above) implicate a non-CO_2 warming agent because CO_2, being gaseous (molecular), disperses efficiently, producing a near-homogenous atmospheric concentration, such that even heavily industrial regions barely (<0.5%) exceed the global average (Zhang et al., 2019, their figure 1). If CO_2 were really Earth's "temperature control knob" (Lacis et al., 2010), modern warming (1940 onward) would be much more uniform spatially. Instead, the gradients incriminate airborne soot because, being particulate, it disperses much less efficiently, remaining concentrated near its mainly *land-based*, *northern-hemisphere* sources, e.g., see figure 1 of Wang et al. (2014). (Antarctica soot emissions are minimal, but see Cordero et al. [2022].) A different model to explain preferential warming over land (observation 2 above) was proposed by Sutton et al. (2007), who suggested that increasing CO_2 produces an essentially uniform increase in radiative forcing over land and ocean, but lesser warming of the latter due to its latent heat of evaporation. However, this hypothesis does not explain why land and ocean warmed in lockstep prior to 1985.

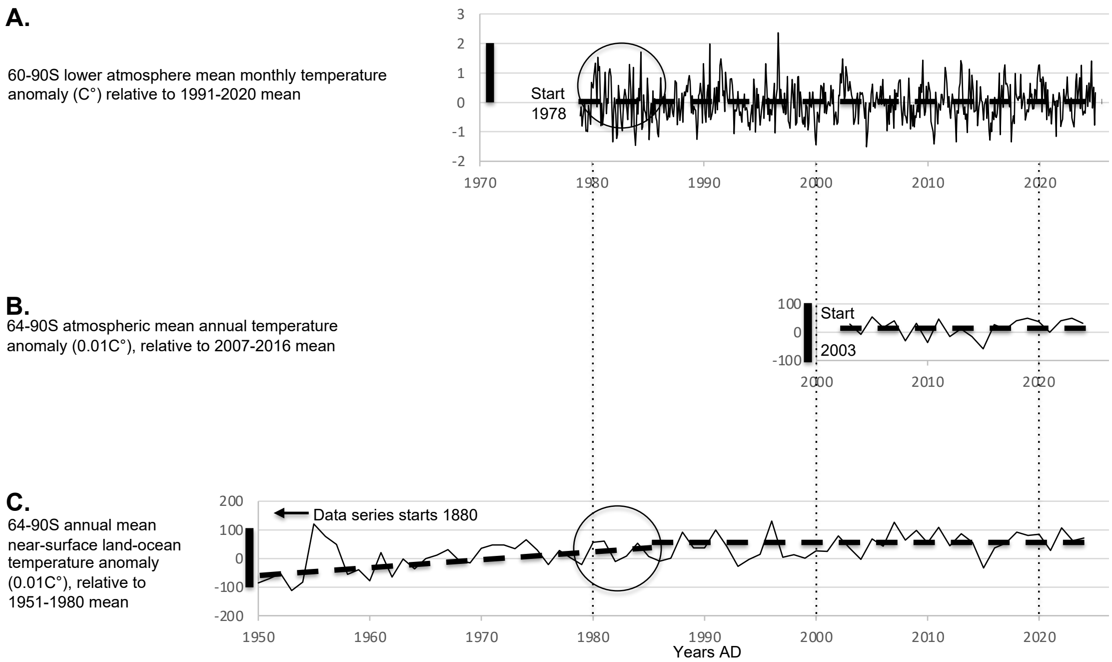

Figure 7. Three graphs (satellite and surface measurements) showing lack of warming in the Antarctic latitudinal belt (64-90°S) since 1980: (A) Latitude 60-90°S TIROS-N satellite-measured lower atmospheric monthly average temperature anomaly, 1978-2024, data of UAH (2025); (B) 64-90°S AIRS satellite-measured mean annual atmospheric temperature anomaly, 2003-2024, data of NASA (2025); and (C) 64-90°S mean annual near-surface-land-air- and sea-surface temperature anomaly, 1950-2024, data of NASA (2025), with "homogeneity adjustment". Vertical scales are equal (heavy bars indicate 1C°). Dashed bars added here are eyeballed average trends. Note lack of any obvious warming (or cooling) trend in any of the graphs since 1980, except graph C, which shows apparent overall warming from 1950 until ~1985, but the temperature-anomaly values in the circle are relatively lower (down-shifted in the graph) than in A, suggesting that the "homogeneity adjustment" is inappropriate.

Excess *ocean* warming since 1994 relative to the corresponding solar output (Figure 6) is here tentatively attributed to airborne soot (albeit much less concentrated than over land) causing a reduction in low-cloud cover (Ackerman et al., 2000; Lohmann et al., 2020), outweighing the predicted (Svensmark) *increase* in cloudiness (expected of the net decline in corresponding solar output; Figure 5A). Indeed, from satellite data, Goessling et al. (2025) demonstrated a decline in global low-cloud cover from 2015-2023 (their figure 2a and f), and suggested that the corresponding loss of cloud reflectivity (albedo) contributed to the global warming recorded in that time interval (cf. Figure 5). Discussing the cause of reduced cloudiness, Goessling et al. (2025) stated that "aerosols ... can influence ... cloud amount" (p. 70) ... [but] ... "isolating the contribution of indirect aerosol effects to cloud amount ... remains challenging" (p. 71). Only two specific aerosols were considered, namely reduced Sahara-derived dust and possibly reduced sulphur emissions from shipping. The possibility of reduced cloud cover due to increased airborne soot was not mentioned. Two lines of evidence tend to incriminate soot in this case. Firstly, the decline in low-cloud cover occurred mostly in latitudes 10°S to 45°N (see figure 3c of Goessling et al. [2025], showing low-cloud cover in those latitudes in 2023 was 2-4% below the 2001-2022 mean), which happens to incorporate the entire 10°S to 45°N southeast Asian region where a large increase in tropospheric mean soot concentration occurred from 1970-2009, especially in China (Allen et al., 2012, figure 1a). Secondly, the 2015 onset of cloud decline (Goessling et al., 2025) began soon (13 years) after the 2002 surge in the growth-rate of world coal consumption (see below), whereby annual consumption rose a remarkable 55% from 2002 to 2014 (cf. Figure 10B), with China accounting for 84% of that increase (OWD, 2025a).

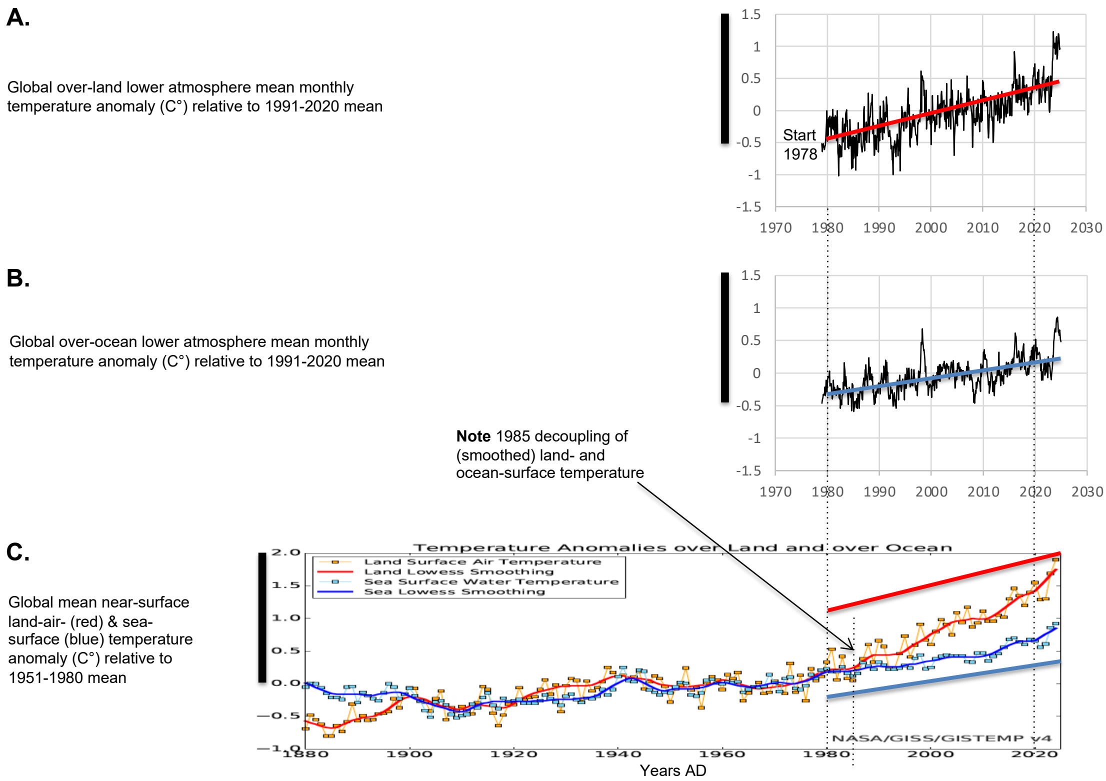

Figure 8. Comparison since 1978 of: (A) satellite-measured global lower atmospheric monthly average temperature anomaly over land and (B) ocean (same UAH [2025] data source as Figure 7A); and (C) near-surface-air temperature anomaly over land and ocean (same chart as Figure 6B). Vertical scales in A, B and C are equal (black bars = 2C°; for less-squeezed version of C, see Figure 6B). Eyeballed red and blue trend-lines in A and B are transferred onto C for comparison of gradients (decadal average warming rates). Atmospheric warming is greater/faster over land (A) than over ocean (B). Note, over land, less warming at altitude (A) than at surface (C). In contrast, there is no discernible differential warming over ocean (B versus C), nor over Antarctica (Figure 7), nor the Southern Hemisphere (SH; Figure 9), confirming reliable calibration of satellite- and surface instruments, and consistent with much less soot over oceans and over SH than over land and NH (see text). Note, in C, terrestrial near-surface air has warmed faster than sea-surface since 1985 (steeper gradient of wiggly red line compared to wiggly blue line), having been in lockstep before.

Anthropogenic soot is produced primarily by the burning of three commodities (Bond et al., 2013, table 8): oil-derived fuels (in cars, buses, trucks, ships, aircraft), especially diesel; coal (mainly in powerplants, steelworks and cementworks); and wood (home-cooking by billions of people lacking electricity). The suspended soot particles are black, hence solar radiation warms them (Jacobson, 2001), in turn warming the surrounding air. Above intensely industrialized regions (e.g., China, Europe, eastern USA), average atmospheric soot concentration is approximately 1000% (i.e., 10 times) greater than over adjacent oceans (NASA, 2011), in stark contrast to CO_2's trivial lateral variations, e.g., 1985-2024 seasonally averaged CO_2 concentration rose from 345 to 425 parts per million (ppm) in Hawaii (SIO, 2025) and 342 to 422 ppm in Tasmania (CSIRO, 2025). Soot also has a strong *vertical* concentration gradient, explaining the slower warming at altitude (observation 6, above), e.g., the global average soot concentration is approximately 100 times greater at 1 km than at 10 km (Cooke et al., 1999, fig. 10), sharply contrasting with CO_2, whose concentration above Tokyo is only 4% less at 4 km than at 1 km (Shibata et al., 2018, fig. 6).

Further evidence of airborne-soot's culpability for most of the 1940-onward excess warming comes from plotting post-1860 annual oil- and coal production (consumption) alongside land- and ocean warming (Figure 10). A good visual match among the graphs is evident. Applying a 10-year temperature-lag provides a logical inter-relation of graph details, as follows:

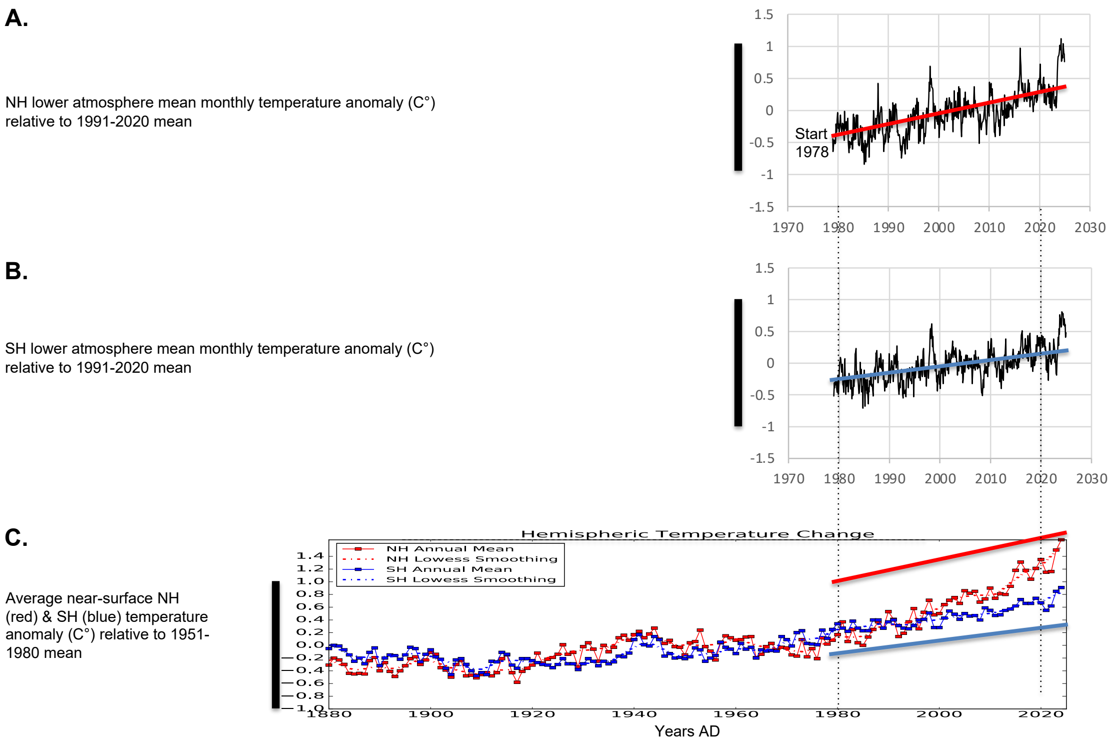

Figure 9. Comparison since 1978 of: (A) satellite-measured global lower atmospheric monthly average temperature anomaly over Northern Hemisphere (NH); and (B) Southern Hemisphere (SH) (same UAH [2025] data source as Figure 7A); and (C) near-surface global temperature anomaly over NH (red) and SH (blue), from NASA (2025). In C, the thin zigzag lines connect the annual values; dash-dot wiggly red and blue lines are 5-year smoothed. Vertical scales in A, B and C are equal (black bars = 2C°; for less-squeezed version of C, see Figure 11C). Eyeballed trend-lines in A and B are transferred onto C for comparison. Atmospheric warming is greater over NH (A) than SH (B). Note, over NH, less warming at altitude (A) than at surface (C). In contrast, there is no such differential warming over SH (B versus C). Note, in C, NH has warmed faster than SH since 1985 (steeper gradient of wiggly red line compared to wiggly blue line), having been in lockstep before.

1. two abrupt jumps (1975 threefold; 2002 about tenfold) in the growth-rate rate of annual global coal consumption (Figure 10B) equate to two leaps (1985, 2012) in the rate of land-warming (Figure 10C; note lack of a 1985-onward *ocean*-warming surge explains the decoupling of the land- and ocean curves);
2. a 1988-1999 period of no coal growth (Figure 10B) essentially aligns with a 2003-2011 pause in global warming (Figure 10C; see Section 4.2, 'Global Warming Hiatus');
3. three other warming-pauses (Figure 10C black bars) align with times of zero- or negative growth of coal- and/or oil (Figure 10A and B black bars), although the second of these pauses can be ascribed to volcanism (see below).

Similar probable cause-and-effect relationships to those pointed out for Figure 10 are seen when the land- and ocean curves are replaced by the NH and SH curves (Figure 11).

The lengths of the four warming-pauses (4-8 years each) suggest they are unrelated to El Niño and La Niña events (typically only 1-2 years [Wikipedia, 2026e]). In two other kinds of internal variability in the climate system, the Atlantic Multi-Decadal Oscillation and the Pacific Decadal Oscillation, the *transitions* between the decades-long warm and cool phases have the right duration (years) but the wrong timing (e.g., graphs in Wikipedia, 2026f, g). The 1991 volcanic super-eruption of Mount Pinatubo caused cooler global temperatures from 1991 through 1993 (Soden et al., 2002), explaining the 1990-1994 warming pause shown by the *five-year-smoothed* temperature curve (Figure 10C). No other large eruption between 1950 and 2020 exceeded about one-tenth the magnitude (volume of erupted tephra) of Pinatubo (Wikipedia, 2026h, i); none has been shown to have caused cooling (i.e., "volcanic winter"; Wikipedia, 2026j). During the longest pause (2003-2011 'Global Warming Hiatus'), no eruption exceeded about one-hundredth the magnitude of Pinatubo (Wikipedia, 2026i). Climate scientists have struggled to explain this hiatus and some even denied its existence (Wikipedia, 2026d). Hansen et al. (2013) stated: "The 5-year mean global temperature has been flat for a decade, which we interpret as a combination of natural variability and a slowdown in the growth rate of the net climate forcing." In contrast, Drijfhout et al. (2014) attributed the hiatus to increased heat uptake across multiple ocean basins.

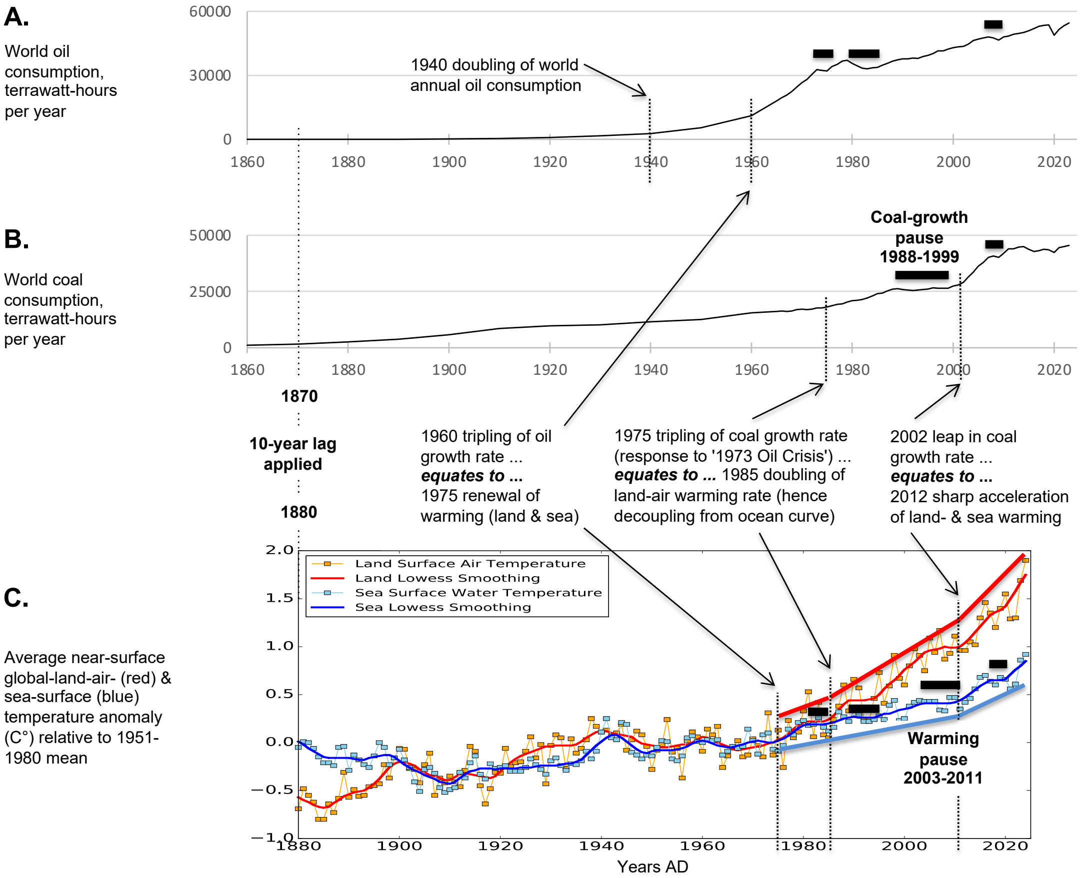

Figure 10. Comparison, from 1880 to 2024, of world (A) annual oil consumption, (B) annual coal consumption, and (C) average near-surface land-air- versus sea-surface temperature anomaly (same chart as Figures 6B and 8C). Data for A and B are from OWD (2025a); data-points are every tenth year until 1960 and annual from 1965 onward. Fair visual match among the three graphs is evident. Applying a 10-year temperature lag (by shifting A and B rightward) produces a logical inter-relation of the three graphs' details (see annotations and text). Heavy black bars indicate warming pauses (graph C, red and blue 5-year-smoothed curves) and intervals of zero or negative growth in oil- and coal consumption (graphs A and B).

Atmospheric CO_2's non-pausing, slightly accelerating rise (Figure 12A) since the 1958 start of systematic measurements cannot explain the warming pauses (Figure 12B). Instead, the stepped rise in global coal- and oil consumption mimics stairstep global warming (Figure 10). The contrast is not evident from the respective correlation coefficients, as both are very high and nearly the same: 0.95 for global temperature (Figure 5B) versus CO_2 (Figure 12A) for 1975 to 2021 (using average annual values, from data sources in the figure captions); and 0.92 for global temperature versus 10-year-lagged annual coal combustion (Figure 10B) for the same time interval. Nevertheless, simple visual inspection shows much greater resemblance between temperature and coal consumption (Figures 10, 11) than between temperature and CO_2 (Figure 12).

Contrary to the general consensus that airborne soot has less warming effect than CO_2, the data and interpretations presented above, including the geographic inequality of warming mentioned earlier, collectively suggest that soot is the main agent of anthropogenic warming and that CO_2 is largely or entirely innocent.

Besides the effect of airborne soot, some of the post-1940 excess (anthropogenic) warmth is possibly by so-called waste heat (thermal pollution by power stations, air conditioners, etc.). Waste heat is considered by some authors to be an important (Chen et al., 2014), or dominant (Bian, 2020), or overwhelming (Karamanev, 2021) source of warming.

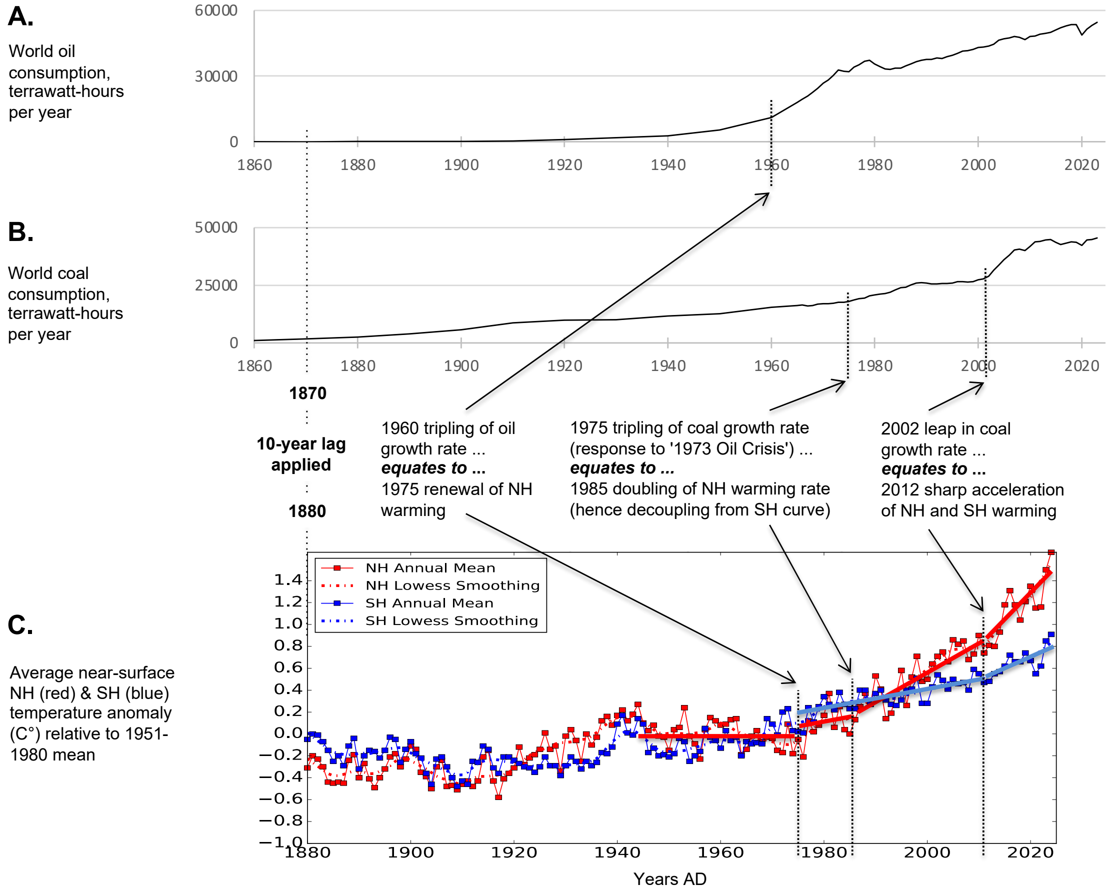

Figure 11. Comparison, from 1880 to 2024, of (A) world annual oil consumption, (B) world annual coal consumption, and (C) Northern Hemisphere (NH) versus Southern (SH) mean annual temperature anomaly. A and B are the same as in Figure 10. Graph C is the same as Figure 9C. A fair visual match among the three graphs is evident. Applying a 10-year temperature-lag (by shifting A and B rightward) produces a logical inter-relation of the three graphs' details (see annotations and text).

5.2. Reasons for Underestimation of Soot Effect and Overestimation of CO_2 Effect

Helping to explain previous underestimations of soot's warming effect, powerplants in the developing-world possibly emit far more soot than the Bond et al. (2013) review assumed. Coal is still the dominant fuel for world electricity generation (35% in 2023; OWD, 2025b). Bond et al. (2013) estimated global coal-fired-powerplant soot emissions to be relatively low (20 Gg/yr, their table 8), because "the high temperatures and well managed combustion promote burnout of any BC [black carbon] that is formed" (p. 5414); but their next sentence admitted "emission rates from power generation in developing countries are not well known" (p. 5414). Bond et al. (2013) then cited Cooke et al. (1999) as having estimated global soot emissions to be ~80 (sic) times higher (i.e., an increase of ~1600 Gg/yr; p. 5414), and they continued "there remains a persistent but informal perception ... that BC fractions of particulate matter in developing countries, especially in power plants and industrial installations, could be higher than that represented by existing measurements. Even if older, poorly operating power plants have high BC emission factors, there is no evidence that newly installed, modern power plants do" (p. 5414-15).

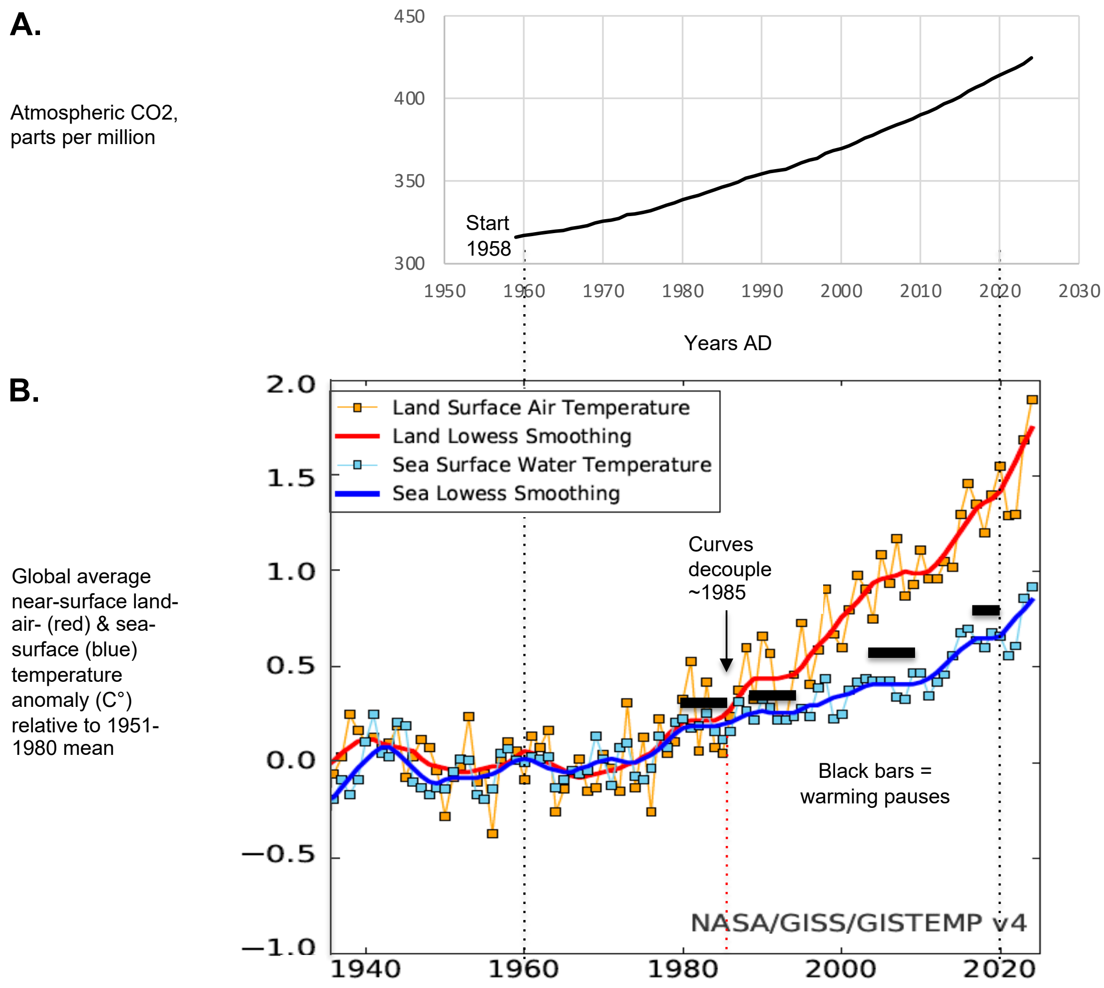

Figure 12. Comparison of (A) annual average atmospheric CO_2 concentration (data from NOAA, 2026) and (B) global annual average near-surface land-air- and sea-surface temperature anomaly (same chart as Figure 6B, 8C and 10C). In (A), CO_2's smooth (slightly accelerating) uninterrupted rise cannot explain, in (B), the decoupling (~1985) of land- and sea temperature curves, or their stepped nature (reflecting warming hiatuses).

Another possible reason for airborne soot having a greater impact on climate than previously supposed is underestimation of soot's effects on clouds (Section 5.1). Bond et al. (2013, figure 35) estimated the net (combined) effect of soot-related positive and negative cloud feedbacks to be positive, but with very large uncertainties.

The above evidence for CO_2 having little effect on temperature implies that its greenhouse effect, already reduced "well into the saturation regime" (van Wijngaarden and Happer, 2020, p. 18) such that " 'instantaneously doubling' CO_2 concentrations ... only decreases radiation to space by about 1% ... [whereas] ... To increase solar heating of the Earth by a few percent, low cloud cover only needs to decrease by a few percent" (van Wijngaarden and Happer, 2025, p. 1), is greatly offset (nullified?) by negative feedbacks excluded or underestimated in climate models. For example, cloud feedbacks are highly uncertain, as detailed by Stephens (2005), whose "critical review of the topic of cloud–climate feedbacks ... exposes some of the underlying reasons for the inherent lack of understanding of these feedbacks" (p. 237). The IPCC (2013a, p. 14) opined that "aerosols and their interactions with clouds have offset a substantial portion of global mean forcing from ... greenhouse gases. They ... contribute the largest uncertainty." Later the IPCC (2014, p. 44) stated: "The radiative forcing from aerosols, which includes cloud adjustments ... has two competing components: a dominant cooling effect from most aerosols and their cloud adjustments and a partially offsetting warming contribution from black carbon absorption of solar radiation.

There is high confidence that the global mean total aerosol radiative forcing has counteracted a substantial portion of radiative forcing from well mixed GHGs [greenhouse gases]. Aerosols continue to contribute the largest uncertainty to the total radiative forcing estimate." A review by Bellouin et al. (2020) found that the magnitude of forcing by aerosols was highly uncertain but that the net effect is probably negative. The most recent IPCC major report confessed that "clouds remain the largest contribution to overall uncertainty in climate feedbacks" but nevertheless concluded that "The net effect of changes in clouds in response to global warming is to amplify human-induced warming, that is, the net cloud feedback is positive (*high confidence*)" (IPCC, 2021b, p. 95; their italics).

One particular cloud-related feedback, certainly negative, is the increase of "Biogenic volatile organic compounds (BVOCs) ... potentially very important" (Kulmala et al., 2013, p. 498). An increase in BVOCs, due to faster forest growth resulting from both warming and increased CO_2 fertilization, raises the concentration of secondary organic aerosol and (thence) cloud concentration nuclei, causing increased cloudiness (Kulmala et al., 2013, 2014; Sporre et al., 2019). In this respect, "we find that the importance of BVOCs ... is greater than previously thought" (Gordon et al., 2017, p. 8739). Sporre et al. (2019, p. 4764) said: "Higher BVOC concentrations result in higher aerosol number and mass concentration, which cool the climate by inducing changes in cloud properties (Twomey, 1974; Albrecht, 1989) ... Higher cloud albedo and longer cloud lifetime lead to decreasing temperature, giving rise to a negative climate feedback."

According to the IPCC (2021c, p. 825), "BVOCs are emitted in large amounts by forests and ... in a warming planet ... are expected to increase but magnitude is unknown and will depend on future land-use change, in addition to climate (*limited evidence, medium agreement*)" (IPCC's italics). The "evaluation of global BVOC emissions is challenging because of poor measurement data coverage in many regions and the lack of year-round measurements. ... Most CMIP6 models use overly simplistic parametrizations and project an increase in global BVOC emissions in response to warming temperatures ... [but] ... do not fully account for the complex processes influencing emissions ... that are hard to constrain observationally" (p. 831). The "assessed central estimate of the climate-BVOC feedback ... suggests that climate-induced increases in SOA [secondary organic aerosols] from BVOCs will lead to a strong cooling effect that will *outweigh the warming from increased ozone and methane lifetime* [italics added here; no mention of potentially also outweighing CO_2's greenhouse warming], however the uncertainty is large" (p. 859). Given all of these uncertainties expressed by the IPCC, and the evidence presented above (and below) for CO_2's relative innocence, it seems likely that climate models favoured by the IPCC have greatly underestimated BVOC negative feedback.

More evidence that CO_2 is relatively benign comes from Murray and Heggie (2016), who found that 1965-2013 warming in the United Kingdom and Japan correlate better with national energy consumption, "a proxy for thermal emission" (p. 298) (i.e., waste heat), than with CO_2-based climate models. During that time period, both the UK and Japan relied heavily on oil-fuels and coal for their total energy requirements (electricity, transport, heating; OWD, 2025a), i.e., their national energy consumption is a proxy for airborne soot as well.

DeConto and Pollard (2016) pointed out that Pliocene atmospheric CO_2 concentrations were comparable to today's (~400 ppm), yet the climate was warmer and some sea-level reconstructions are 10–30 m higher; and that during the more recent Last Interglacial, global mean sea level was 6–9.3 m higher than it is today, at a time when atmospheric CO_2 concentrations were below 280 ppm and global mean temperatures were ~0–2C° warmer.

Further adding to the collective evidence for CO_2's benignity, changes in the growth rate of atmospheric CO_2 *lag behind* changes in the rate of warming or cooling, by ~5 months (Kuo et al., 1990; instrumental monthly data for 1958-1989) or 9.5-12 months (Humlum et al., 2013; data for 1982-2012). For a longer interval, 1 to 1850 AD, based on rigorous statistical analysis of published proxy data, Grabyan (2025) found that CO_2 consistently lags temperature by ~150 years. Citing other authors' reports of CO_2 lags ranging from months in the modern instrumental era, through centuries, to millions of years in Phanerozoic time, Grabyan (2025) concluded that "atmospheric CO_2 does not precede, nor appear to drive, global temperature trends" (p. 35) and "Collectively, these findings, combined with the ~150 yr lag identified here, suggest that different but related processes drive the CO_2–temperature lag at different timescales" (p. 64).

All of the foregoing lines of evidence reinforce the finding of a recent multi-authored, peer-reviewed synthesis: "We conclude that the anthropogenic CO_2-Global Warming hypothesis lacks empirical substantiation, overshadowed by natural drivers such as temperature feedbacks and solar variability, necessitating a fundamental re-evaluation of current climate paradigms" (Grok 3 et al., 2025, p. 13).

5.3. Measures to End Anthropogenic Warming

If soot is indeed the main anthropogenic warming agent, then stopping global warming is technically (but not politically) easy: freezing global oil- and coal combustion at the current annual rate would halt airborne-soot *growth*, thereby halting anthropogenic warming in ~10 years (lag-time in Figure 10). Going further and *reducing* consumption would hypothetically cause cooling, in the absence of any solar increase (but see below). Lohmann et al. (2020, p. 674) concurred: "Our findings suggest that reducing emissions of soot particles is beneficial for future climate, in addition to air quality and human health." However, in reality, consumption will probably continue to rise, as developing nations strive to grow their economies and their armed forces. For example, from 2005 to 2023, China's annual coal usage grew 65% while the United Kingdom's shrank 90% (OWD, 2025a). In 2023, China, with 20 times the UK population, burned 500 (sic) times as much coal. Furthermore, the exceptional doubling of solar-magnetic output from 1901 to 1992 (Lockwood et al., 1999, fig. 3), to its highest level in >2,000 years (see 1992 red peak in figure 14 of Wu et al. [2018]), means that Sun-driven warming will start adding to anthropogenic warming after ~2060, with a maximum contribution ~2150 (~160-year lag, Figures 4 and 5).

Given the collectively strong evidence that rising CO_2 causes little if any global warming, governments should urgently implement proper measures toward ending anthropogenic warming, namely by curbing soot emissions. These measures *might* also limit the coming severe sea-level rise. (Unfortunately, even if warming were stopped today, a sea-level rise of at least 3 m by 2100 now appears inevitable [Higgs 2024, 2026a, b, c].) Knowing that the main culprit is soot, not CO_2, justifies generating much more of the world's electricity using natural gas (only 22% in 2023, versus coal 35% and oil 3% [OWD, 2025b]). Natural gas emits CO_2 but almost no soot when properly combusted. New gas-fired capacity could replace existing coal (36%) and nuclear-fission powerplants (9%), with the additional double-benefit of improving air quality and terminating growth of radioactive waste.

CO_2's innocence would render wind turbines (8%) and solar panels (5%) triply indefensible: (a) intermittent; (b) sequestration of priceless land (agriculture, housing, natural habitats, aesthetic beauty); and (c) vast disposal problem (most going to landfill). Carbon capture becomes triply foolhardy: (a) needless; (b) waste of trillions of dollars; and (c) will retard CO_2-fertilisation of crops and forests. (At 425 ppm in late 2025, CO_2 is still only ~40% of the ~1,000 ppm optimum for plant growth [e.g., Zheng et al., 2018] and is exceptionally low in terms of the last 500 million years [e.g., Berner and Kothavala, 2001].) Proposed climate alteration by "solar radiation modification" (Wikipedia, 2026k), with highly uncertain consequences, likewise becomes a needless, hugely expensive, potentially hazardous exercise.

If soot is indeed a far stronger warming agent than CO_2, no new coal-, wind-, solar-, or nuclear-fission powerplants should be built, only gas-fired ones. Global *proven* gas reserves would last ~50 years at the current consumption rate (OWD, 2025c), or ~25 years at twice that rate. *Probable* reserves, automatically classed as proven as soon as higher prices render them economically recoverable, would last additional decades. By then, nuclear-*fusion* energy, limitless and clean (no soot or radioactive-waste; nor CO_2), might be a reality; and CO_2 will be nearer the optimum. However, as insurance, increased exploration for (low-soot) gas would be prudent.

The simplest, fastest, and most obvious way to reduce energy consumption is personal conservation, widely ignored by society. For example, in many western households with one or two parents and one or two grown children, each of them has a car. Individuals could opt to purchase far fewer non-essential products, especially those made in China (electricity 61% coal-generated in 2023, versus UK 1% [OWD, 2025b]) which, moreover, necessitate long-distance diesel-powered shipment. Millions of people fly excessively and needlessly, including the author.

6. Conclusions

Graphs of global temperature and solar output match well for the last 9,000 years, with a temperature lag of ~150 years attributable to ocean thermal inertia. The graphs recently became decoupled, whereby 1940 onward was disproportionately warm for the corresponding solar output, suggesting that humanity added warmth. Post-1985 warming is geographically unequal (land versus ocean; northern- versus southern hemisphere), implicating human-emitted airborne soot which, unlike atmospherically well-mixed CO_2, lingers near its primarily land-based, northern-hemisphere sources, mainly comprising domestic and industrial burning of diesel oil, coal and wood. Apparently, CO_2's greenhouse effect is offset by feedbacks underestimated in climate models. Simply freezing world oil- and coal combustion at today's level, thereby halting airborne-soot growth, would potentially end anthropogenic warming in ~10 years; going further and *reducing* coal usage would hypothetically have a cooling effect, which will counteract (time-lagged) Sun-driven warming, predicted to resume a few decades from now. To reduce coal consumption, coal should be replaced by natural gas (almost soot-free) for generating electricity. World gas reserves are sufficient for decades, perhaps long enough for development of clean, nuclear-fusion energy.

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