

Reproducing the Mid-Piacenzian Warm Period Climate in the 2020s.

By

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Abstract.

The current expectation of climatologists is that levels of atmospheric carbon dioxide (CO₂) and other greenhouse gases, such as methane (CH₄) and nitrous oxide (N₂O), will correspond, in the 2020s, to an increase in mean annual global near-surface atmospheric temperature of less than 1.5°C above the pre-industrial Holocene norm (1750 baseline; atmospheric CO₂ = 278 ppm). This paper will argue, contrarily, that it is not possible to reproduce the atmospheric chemistry of the Mid-Piacenzian Warm Period (3.3-3 Mya) of the Pliocene Epoch, 5.3-2.588 Mya, without also reproducing its climate, and that – consequently – we can expect to see global warming of 3°C this decade.

Keywords: climate; anthropogenic climate change; carbon dioxide (CO₂); other greenhouse gases; global warming; Mid-Piacenzian Warm Period; Pliocene Epoch; transient *versus* equilibrium climates.

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1. Introduction.

It shall be argued in this paper that reproducing the atmospheric chemistry of the Mid-Piacenzian Warm Period (3.3-3 Mya; hereinafter MPWP) of the Pliocene Epoch is liable, *ceteris paribus*, to reproduce

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the climatic conditions of that period, and that the same applies to any other period or epoch of the geological past.

The qualification is important: it is not argued here that merely replicating previous high levels of carbon dioxide will result automatically in high surface temperatures if, for example, the Earth's orbital parameters (eccentricity, obliquity and precession)² were to be like those prevailing in the Pleistocene glacial periods. However, it is accepted (by Haywood, Dowsett and Dolan, 2016; de la Vega *et al*, 2020; and Samakinwa, Stepanek and Lohmann, 2020) that the KM5c marine isotope stage (see Tan *et al*, 2020), 3.205 Mya, corresponds to a time when Earth had the same orbital configuration as it does today, and in contrast to the Pleistocene Epoch, the Ice Ages of which resulted from the cycles in Earth's orbital parameters identified by Milankovitch (Milanković, 1941, 1969).

Using the formula derived from Schröder and Connon Smith (2008, p.3), which stipulates that solar luminosity increases by 1% every 110 million years, we can calculate that, 3.205 million years ago, the Sun was 0.029% less luminous than it is today.

All scholars are agreed that atmospheric carbon dioxide (CO₂) levels during the MPWP are comparable to today's, with de la Vega *et al* (op.cit.) claiming that they reached a maximum of 421 ppm during the KM5c interglacial, corresponding to a mean annual global near-surface atmospheric temperature ~3°C above the pre-industrial Holocene norm. The US National Oceanographic and Atmospheric Administration (NOAA, 2023) reports that, in August 2023, atmospheric CO₂ reached 419.68 ppm, having been as high as 424 ppm in May of this year. The 'de-seasonalised' figures for May-August 2023 are 420.55 ppm, 421.19 ppm, 421.42 ppm and 421.62 ppm, respectively.

2. Equilibrium versus Transient Climates.

It is argued that the MPWP was an equilibrium climate, and so is not, or not strictly, comparable to today's climate, which is a transient one (Sun *et al*, 2023). The parallel is between equilibrium climate sensitivity (ECS), which is the change in surface atmospheric

² The Earth's orbital eccentricity cycle (also known as its *apsidal precession*) takes ~112,000 years; its obliquity (axial tilt) cycle takes 41,000 years; and its precession cycle takes 25,771.5 years – see Buis (2020).

temperature (SAT) in response³ to a doubling of CO₂, and transient climate response (TCR). However, as King *et al* (2019) note, this difference can, in fact, mean that transient climates are *warmer* than equilibrium ones, not cooler.

Total solar irradiance (TSI), otherwise known as the solar constant, or insolation, is the average amount of solar electromagnetic radiation, measured over the entire spectrum, incident upon unit area of a surface of the Earth perpendicular to the Sun's rays, at a distance of one astronomical unit (~100 million kilometres), from the Sun during the course of one year, and is 1.361 kW m⁻² (Kopp and Lean, 2011). The cross-sectional area of the planet's surface exposed to the Sun's rays annually is one quarter of TSI, which is 340.25 W m⁻². Schmutz (2021) discusses the relationship between reconstructed TSI and climate (specifically March temperature records from Kyoto, Japan) for the 660 year period from 1230 to 1890, and concludes that the TSI can decrease by up to 10 W m⁻² during Maunder Minimum 'cold climate excursions' (p.1). Schurer, Tett and Hegerl (2013), however, concluded that solar forcing probably had a minor effect on Northern Hemisphere climate over the past millennium. We have already seen that solar luminosity was slightly lower than its present value during the MPWP, so solar forcing, as well as orbital forcing, cannot account for the higher mean annual global surface temperature at that time.

The difference between the amount of energy Earth receives from the Sun and that which it reflects back out into space is the Earth Energy Imbalance (EEI), and it is both positive and growing in size, with 89% of the heat stored in the oceans and seas, 6% on land, 1% in the atmosphere, and 4% available for melting the cryosphere (polar ice caps + glaciers and permafrost). The heating rate amounts to ~0.76 W m⁻² over the most recent period measured, 2006-2020, and the total heat energy accumulated from 1971-2020 amounted to ~381 ZJ (zettajoules; 1 ZJ = 10²¹, or 1 sextillion joules); see von Schuckmann *et al* (2023). This will have contributed to the record high global sea surface temperatures (SSTs) reported for August of this year by the European Union's Copernicus Climate Change Service (2023), reaching 21.02°C

³ If ice sheets, vegetation and other long-lived greenhouse gases are fixed – see Hansen *et al* (2023, p.4).

on the 23rd and 24th August. The North Atlantic Ocean reached a record high of 25.19°C on the 31st August.

At the same time, as the NASA Earth Observatory (2023) reported in August, Antarctic sea-ice extent, which should be increasing by over 15 million km² in the Austral Winter, averaged only an additional 13.5 million km² throughout July, 2 million km² less than the 1981-2010 average, and 1.5 million km² less than the previous record low of July 2022.

The US National Snow and Ice Data Center (NSIDC, 2023) informs us that, in August of this year, Arctic sea-ice extent (Boreal Summer) averaged 5.57 million km², 1.63 million km² below the 1981-2010 reference period.

Chenal, Meyssignac, Ribes and Guillaume-Castel (2022) discuss the relationship between EEI and what they term the ‘effective climate sensitivity to CO₂’, which they estimate to be 5.46 K (= °C), and which differs from ECS because it only includes CO₂, like ECS is run for 150 years under an abrupt quadrupling of the gas, but unlike ECS ignores the carbon cycle and ice-sheet responses and that of ocean and sea ice beyond 150 years. It is obtained, they say, by

‘regressing top-of-the-atmosphere (TOA) radiative imbalance against SAT [surface air temperature] and then linearly extrapolating to determine the temperature at which the radiative imbalance is zero.’

It should be noted that the variable λ they use is not the same as the one used below, but is a negative climate feedback parameter, measured in W m⁻² K⁻¹.

The polar ice sheets in the MPWP were much smaller than those of present-day, and sea-levels were ~20 m higher (Dumitru *et al*, 2019; de la Vega *et al*, op.cit.). Salzmann *et al* (2011) note the MPWP was not only warmer than present-day conditions, but wetter, and that temperate and boreal vegetation zones were shifted northwards from their present positions. Sun *et al* (2023) concur, finding considerable warming in the higher latitudes, a wetter climate, but less warming in the tropics.

Hargreaves and Annan (2016) ask if the MPWP can constrain ECS, and conclude that it yields a range of 1.9-3.7°C. Ring, Mutz and Ehlers (2022) argue that:

‘when paleoclimate models are forced with early Eocene boundary conditions (dimmer sun, vegetation distribution, continental configuration, and a lack of ice sheets) but preindustrial greenhouse gas concentration, simulated [global surface temperature response] tends to be around 5°C warmer than simulations of the present-day Earth.’

They therefore argue for a broader measure than ECS, Earth System Sensitivity (ESS), which takes account of slow climate feedbacks, as well as faster ones. They claim there was a two-fold increase in the ESS at some time during the Pliocene and Pleistocene Epochs. They derive a value for ESS of 3-4.7°C for every doubling of CO₂.

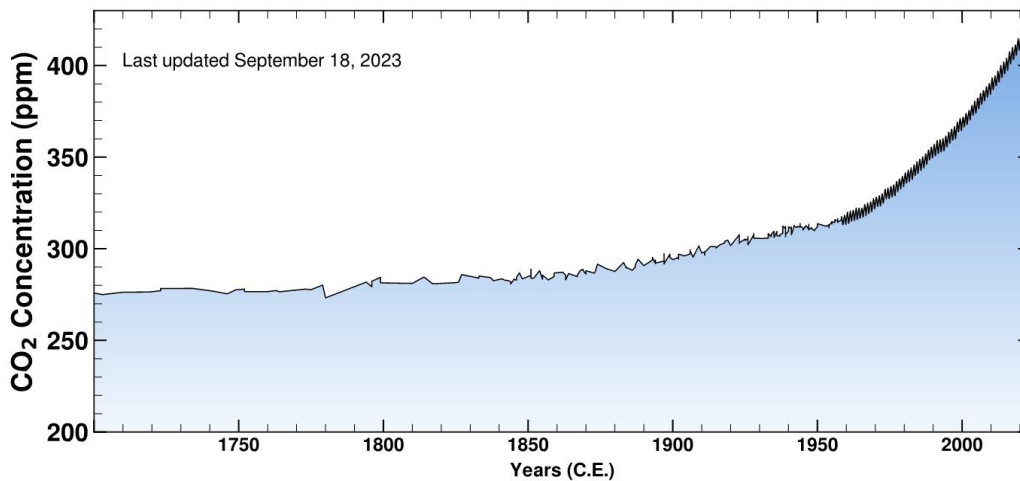
Tierney *et al* (2019), agreeing with Sun *et al* (op.cit.) regarding the modest warming of the Pliocene tropics (only about 1°C warmer than present value) and noting there was no permanent ‘El Niño’, as predicted by some climate models, say that higher CO₂, along with (consequent) changes in ice and vegetation, and some differences in topography, are enough to explain Pliocene climate.

Hansen *et al* (op.cit.) claim that ECS is ~1.2°C m² W⁻¹. Full climate forcing (CO₂ + non-CO₂) of 4.1 W m⁻² would, they say, result in ‘equilibrium global warming’ of 10°C, but this is reduced to 8°C by contemporary aerosols. They argue the decline in aerosol emissions since 2010 should increase the post-2010 global warming rate to at least 0.27°C per decade, and that the 2015 Paris Agreement target of 1.5°C will be exceeded in the 2020s, with the 2°C target before 2050. They note that the IPCC has a mean estimate for ECS of ~3°C (see Forster *et al*, 2021, p.926; they argue it is ‘virtually certain’ to be >1.5°C, and the ‘very likely’ range is 2-5°C, while the ‘likely’ range is 2-4°C, *ibid.*). Air quality improvement legislation is likely to reduce anthropogenic aerosol emissions, as Hienola *et al* (2018) argue, and this, as they say, could make global warming ‘noticeably faster and stronger.’

Rugenstein *et al* (2019) define the ECS as:

‘the global- and time-mean, surface air warming once radiative equilibrium is reached in response to doubling the atmospheric CO₂ concentration above pre-industrial levels.’

They give an estimate for ECS of between 2.42-5.83 K (°C, p.4). The graph below (from the Scripps Institution of Oceanography, 2023) shows how atmospheric CO₂ has increased from 278 ppm in 1750 to ~420 ppm in 2023, an increase of 51.079% in 273 years – almost all of it since 1960, i.e., in the last 63 of those years⁴.



3. Discussion.

There may well be some confusion regarding what units ECS is measured in, whether it be °C, K, or °C m² W⁻¹. In reality, for this purpose, °C and K are equivalent, although the former is to be preferred, as the Paris Agreement targets are measured in Celsius, and that temperature scale is the one used by the IPCC and UNFCCC. With regard to the latter, it is multiplied by a climate forcing, measured in W m⁻², to obtain an ECS measured in °C.

Using the formula discovered by Arrhenius (1895, 1896), we determine that the increase in mean annual near-surface atmospheric temperature since 1750 (CO₂ = 278 ppm), ΔT , is given by:

$$\Delta T = \Delta F \times \lambda \times \log_n(C/278) .$$

Here, ΔF is the climate forcing and λ is the ECS, measured in °C m² W⁻¹. C is then the current atmospheric level of CO₂ (we are here

⁴ On a personal note, the present author will be celebrating his 67th birthday on the 1st November of this year, so will have been alive for all but four of those years. He would also like to state that he very much hopes that what is presented here will prove to be wildly incorrect, but fears that it will be only-too-thoroughly vindicated.

ignoring other greenhouse gases). It is obviously easier to deal with an ECS that it is the product of $\lambda \cdot \Delta F$, so that shall be our usage from now onwards, symbolised by Λ .

If the MPWP achieved global warming – that is to say, a mean annual global near-surface atmospheric temperature $\sim 3^\circ\text{C}$ above the 1750 level (13.42°C , only 0.3°C below the 1900 level, illustrative of the small degree of change over that 150 year period⁵) – that would have corresponded to a similar CO_2 baseline of 278 ppm. The maximum during the KM5c marine isotope stage of the MPWP, 3.205 Mya, as we have seen (p.2), was 421 ppm (de la Vega *et al*, op.cit.). However, this leads us to only one – ad one quite horrifying – conclusion – as we shall see.

4. Conclusion.

The conclusion we are forced to draw from the above is straightforward, but one many will find distressing and profoundly discomfoting, and it is this: if we re-arrange the above equation to obtain a value for Λ in the KM5c stage of the MPWP, we get

$$\Lambda = 3^\circ\text{C}/\log_n(421/278) = 7.2287^\circ\text{C} .$$

This is well above the ECS given by Hargreaves and Annan (op.cit.), Rugenstein *et al* (op.cit.) and Forster *et al* (op.cit.), but is less than the 8.55 K (= $^\circ\text{C}$) ECS outlier identified, and rejected by, Rugenstein and her colleagues (p.4, *ibid.*)⁶. It is also above that given by Hansen *et al*, the figure for ESS supplied by Ring, Mutz and Ehlers (op.cit.), and that for ‘effective CO_2 climate sensivity’ given by Chenal, Meyssignac, Ribes and Guillaume-Castel (op.cit.).

The result will be stark: if this ECS is replicated in the 21st Century – and there is no reason to doubt that it *will* be – then global warming will reach 3°C , not at the end of the century, but this decade – in fact, within the next year or so, see NOAA Global Monitoring Laboratory (op.cit.). If Hansen *et al* are right in their estimation of the value of GHG forcing, namely 4.1 W m^{-2} , that only requires a figure

⁵ See: <https://arctic-news.blogspot.com/p/temperature.html>.

⁶ They accept that it is permitted by the physics, but reject it on probabilistic grounds.

for λ of $1.7631 \text{ }^\circ\text{C m}^2 \text{ W}^{-1}$, rather than $1.2 \text{ }^\circ\text{C m}^2 \text{ W}^{-1}$, to produce the value for Λ given above.

There is, therefore, absolutely no room for the sort of complacency about the climate emergency displayed by the British Prime Minister, Rishi Sunak, or the British Opposition Leader, Sir Keir Starmer, recently (see Stacey and Savage, 2023; Blewett, 2023). On the contrary, we need an immediate, global, end to the burning of fossil fuels, to deforestation, and to the destruction of wetlands.

There can be little doubt that none of these things will occur, and therefore no grounds at all for optimism regarding the future of our species. However, nature is nothing if not resilient, and the possible extinction – or severe culling – of our species may lead to the survival, and flourishing, of many others that have hitherto faced oblivion. That, at any rate, is cause for optimism for all but the most purblind of anthropocentrists.

References.

Arrhenius, S., ‘On the influence of carbonic acid in the air upon the temperature of the ground,’ *The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science, Series 5* **41(251):237-276**, 1896, extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December 1895,
http://geosci.uchicago.edu/~archer/warming_papers/archer_galleys/9781405196178_4_003a.pdf.

Blewett, S., ‘Just Stop Oil’s demands are “contemptible”, says Starmer,’ *The Independent*, Sunday 6th August 2023,
<https://www.independent.co.uk/news/uk/politics/keir-starmer-just-stop-oil-labour-b2388586.html>.

Buis, A., ‘Milankovitch (Orbital) Cycles and Their Role in Earth’s Climate,’ *NASA Global Climate Change*, 27th February 2020,
<https://climate.nasa.gov/news/2948/milankovitch-orbital-cycles-and-their-role-in-earths-climate/>.

Chenal, J., Meyssignac, B., Ribes, A. & Guillaume-Castel, R., ‘Observational Constraint on the Climate Sensitivity to Atmospheric CO₂ Concentrations Changes Derived from the 1971-2017 Global

Energy Budget,' *Journal of Climate* **35(14):4469-4483**, 10th June 2022 (online), 15th July 2022 (print),
DOI: 10.1175/JCLI-D-21-0565.1,
<https://journals.ametsoc.org/view/journals/clim/35/14/JCLI-D-21-0565.1.xml>.

Copernicus Climate Change Service (2023), 'Record high global sea surface temperatures continue in August,' August 2023 Climate Bulletins Update, 5th September 2023,
<https://climate.copernicus.eu/record-high-global-sea-surface-temperatures-continue-august>.

de la Vega, E., Chalk, T.B., Wilson, P.A., Bysani, R.P. & Foster, G.L., 'Atmospheric CO₂ during the Mid-Piacenzian Warm Period and the M2 glaciation,' *Nature Scientific Reports* **10:11002** (article number), 9th July 2020, DOI: 10.1038/s41598-020-67154-8,
<https://www.nature.com/articles/s41598-%202020-67154-8>.

Dumitru, O.A., Austermann, J., Polyak, V.J., Fornós, J.J., Asmerom, Y., *et al*, 'Constraints on global mean sea level during Pliocene warmth,' *Nature* **574(7777):233-236**, 30th August 2019 (issue date 10th October 2019), DOI: 10.1038/s41586-019-1543-2,
https://www.cuevasdearta.com/backoffice/pdf/files/44nature-articulo_en.pdf.

Forster, P., Storelvmo, T., Armour, K., Collins, W., Dufresne, J.-L., *et al*, 'The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity,' in Mason-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., *et al*, eds., *Climate Change 2021: Contribution of Working Group I to the Sixth Assessment Report [AR6] of the Intergovernmental Panel on Climate Change [IPCC]*, Cambridge: Cambridge University Press (CUP), Ch.7, pp.923-1054, DOI: 10.1017/9781009157896.009.,
https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter07.pdf.

Hansen, J.E., Sato, M., Simons, L., Nazarenko, L.S., Sangha, I., *et al*, 'Global warming in the pipeline,' version 3, *arXiv*, 23rd May 2023,
<https://arxiv.org/ftp/arxiv/papers/2212/2212.04474.pdf>.

Hargreaves, J.C. & Annan, J.D., ‘Could the Pliocene constrain the equilibrium climate sensitivity?’, *Climate of the Past* **12(8):1591-1599**, 1st August 2016, DOI: 10.5194/cp-12-1591-2016, <https://cp.copernicus.org/articles/12/1591/2016/cp-12-1591-2016.pdf>.

Haywood, A.M., Dowsett, H.J. & Dolan, A.M., ‘Integrating geological archives and climate models for the mid-Pliocene warm period,’ *Nature Communications* **7:10646** (article number), 16th February 2016, DOI: 10.1038/ncomms10646, <https://www.nature.com/articles/ncomms10646>.

Hienola, A., Partanen, A.-I., Pietikäinen, J.-P., O’Donnell, D., Korhonen, H., *et al*, ‘The impact of aerosol emissions on the 1.5°C pathways,’ *Environmental Research Letters* **13(4):044011** (article number), 26th March 2018, DOI: 10.1088/1748-9326/aab1b2, <https://iopscience.iop.org/article/10.1088/1748-9326/aab1b2/pdf>.

King, A.D., Lane, T.P., Henley, B.J. & Brown, J.R., ‘Global and regional impacts differ between transient and equilibrium warmer worlds,’ *Nature Climate Change* **10:42-47**, 23rd December 2019 (issue date January 2020), DOI: 10.1038/s41558-019-0658-7, <https://rest.neptune-prod.its.unimelb.edu.au/server/api/core/bitstreams/82a36936-885a-573c-add3-8fa99b95794b/content>.

Kopp, G. & Lean, J.L., ‘A new, lower value of total solar irradiance: Evidence and climate significance,’ *Geophysical Research Letters* **38(1):L01706** (article number), 14th January 2011, DOI: 10.1029/2010GL045777, <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2010GL045777>.

Milankovitch (Milanković), M. (1941, 1969), *Canon of Insolation and the Ice-age Problem (Kanon der Erdbestrahlung und seine Anwendung auf das Eiszeitenproblem)*, Israel Program for Scientific Translations, Springfield, Virginia, USA: US Department of Commerce Clearinghouse for Federal Scientific and Technical Information.

NASA Earth Observatory (2023), 'Exceptionally Low Antarctic Sea Ice,' 7th August 2023,
<https://earthobservatory.nasa.gov/images/151692/exceptionally-low-antarctic-sea-ice>.

NOAA Global Monitoring Laboratory Earth System Laboratories
Trends in Atmospheric Carbon Dioxide, 2023,
https://gml.noaa.gov/webdata/ccgg/trends/co2/co2_mm_mlo.txt.

NSIDC (2023), 'Arctic Sea Ice News and Analysis: Late summer heat wave avoids central Arctic,' 5th September 2023,
<http://nsidc.org/arcticseaicenews/2023/09/late-summer-heat-wave-arctic/>.

Ring, S.J., Mutz, S.G. & Ehlers, T.A., 'Cenozoic Proxy Constraints on Earth System Sensitivity to Greenhouse Gases,' *Paleoceanography and Paleoclimatology* **37(12):e2021PA004364** (article number), 1st December 2022, DOI: 10.1029/2021PA004364,
<https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021PA004364>.

Rugenstein, M., Bloch-Johnson, J., Gregory, J., Andrews, T., Mauritsen, T., *et al*, 'Equilibrium Climate Sensitivity Estimated by Equilibrating Climate Models,' *Geophysical Research Letters* **47(4):e2019GL083898** (article number), 19th November 2019 (issue date 28th February 2020), DOI: 10.1029/2019GL083898,
<https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2019GL083898>.

Salzmann, U., Williams, M., Haywood, A., Johnson, A., Kender, S. & Zalasiewicz, J., 'Climate and environment in a Pliocene warm world,' *Palaeogeography, Palaeoclimatology, Palaeoecology* **309(1-2):1-8**, 15th August 2011, DOI: 10.1016/j.palaeo.2011.05.044, ISSN: 0031-0182,
<https://researchportal.northumbria.ac.uk/ws/portalfiles/portal/3020162/salzmann.pdf>.

Samakinwa, E., Stepanek, C. & Lohmann, G., 'Sensitivity of mid-Pliocene climate to changes in orbital forcing and Pliocene boundary

conditions,' *Climate of the Past* **16(4):1643-1665**, 27th August 2020, DOI: 10.5194/cp-16-1643-2020, <https://cp.copernicus.org/articles/16/1643/2020/cp-16-1643-2020.pdf>.

Schmutz, W.K., 'Changes in the Total Solar Irradiance and climatic effects,' *Journal of Space Weather and Space Climate* **11:40** (article number), 22nd July 2021, DOI: 10.1051/swsc/2021016, <https://www.swsc-journal.org/articles/swsc/pdf/2021/01/swsc200108.pdf>.

Schröder, K.-P. & Connon Smith, R., 'Distant future of the Sun and Earth revisited,' *Monthly Notices of the Royal Astronomical Society (MNRAS)* **386(1):155-163**, 13th March 2008, DOI: 10.1111/j.1365-2966.2008.13022.x, <https://physics-lectures.tripod.com/future.pdf>.

Schurer, A.P., Tett, S.F.B. & Hegerl, G.C., 'Small influence of solar variability on climate over the past millennium,' *Nature Geoscience* **7:104-108**, 22nd December 2013 (issue date February 2014), DOI: 10.1038/ngeo2040, abstract only at: <https://www.nature.com/articles/ngeo2040>.

Scripps Institution of Oceanography, University of California, San Diego, California, USA, Keeling Curve Graphs in PDF Format, 1700-Present, last updated 18th September 2023, https://bluemoon.ucsd.edu/co2_400/co2_800k_zoom.pdf.

Stacey, K. & Savage, M., 'Rishi Sunak tells G20: UK will resist "hair shirt" policies on net zero pledge,' *The Guardian*, Saturday 9th September 2023, <https://www.theguardian.com/politics/2023/sep/09/rishi-sunak-tells-g20-uk-will-resist-hair-shirt-policies-on-net-zero-pledge>.

Sun, Y., Su, B., Dowsett, H., Wu, H. & Ramstein, G., 'Modeling the mid-Piacenzian warm climate using the water isotope-enabled Community Earth System Model (iCESM1.2),' *Research Square*, 24th January 2023, DOI: 10.21203/rs.3.rs-2493377/v1, https://assets.researchsquare.com/files/rs-2493377/v1_covered.pdf?c=1674583475.

Tan, N., Contoux, C., Ramstein, G., Sun, Y., Dumas, C., *et al*, 'Modeling a modern-like $p\text{CO}_2$ warm period (Marine Isotope Stage KM5c) with two versions of an Institut Pierre Simon Laplace atmosphere-ocean coupled general circulation model,' *Climate of the Past* **16(1):1-16**, 6th January 2020, DOI: 10.5194/cp-16-1-2020, <https://cp.copernicus.org/articles/16/1/2020/>.

Tierney, J.E., Haywood, A.M., Feng, R., Bhattacharya, T. & Otto-Bliesner, B.L., 'Pliocene Warmth Consistent With Greenhouse Gas Forcing,' *Geophysical Research Letters* **46(15):9136-9144**, 1st August 2019, DOI: 10.1029/2019GL083802, <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019GL083802>.

von Schuckmann, K., Minière, A., Gues, F., Cuesta-Valero, F.J., Kirchengast, G., *et al*, 'Heat stored in the Earth system 1960-2020: where does the energy go?', *Earth System Science Data* **15(4):1675-1709**, 17th April 2023, DOI: 10.5194/essd-15-1675-2023, <https://essd.copernicus.org/articles/15/1675/2023/>.