**Setting the scene**

Before engaging with Hansen and colleagues’ *Warming in the Pipeline* paper (hereafter *WinP*), so alarming is their message that it may help those not familiar with the science of global warming to understand a little of the basic physics at its core. Others may skip this section.

Global warming refers to the rising temperature at or close to the planet’s surface and in the top 100m or so of the ocean. This is the zone where almost all life is to be found. It arises because more energy enters the top of the atmosphere (TOA) from the sun than escapes from Earth into outer space[[1]](#footnote-1). Solar energy arrives mostly in the form of visible light. A bit less than one third of that energy is immediately reflected back to outer space, mostly by clouds and surfaces covered by ice and snow. Most of the remaining solar energy reaching the surface is converted into heat and some is used by plants as the energy source for the creation of biomass.

Like any other body that is warmer than its surroundings, planet Earth radiates heat to outer space. Currently, the difference between the light and heat radiated out and the sunlight radiated in, is about 1 Watt per square metre (W/m2), sufficient to power one tiny LED. However, when taken across the entire Earth’s surface, in one year this 1 W/m2 amounts to about 25 times the combined annual energy produced by humans from wood, coal, oil, gas, nuclear, hydro, geothermal and renewables. This energy imbalance at TOA is known as Earth Energy Imbalance (EEI). For global warming to be arrested, EEI must be reduced at least to zero. For the warming to stop soon or for the planet to cool, EEI must be reduced beyond zero producing a net energy outflow to outer space. For this to happen, either more sunlight must be reflected back to outer space before it warms Earth’s surface, or more heat radiated from the surface must be allowed to escape to outer space[[2]](#footnote-2).

Methods that work by reflecting sunlight are broadly known as *solar radiation management* or *modification (SRM)*, *albedo enhancement (AE)[[3]](#footnote-3)* or simply *planetary cooling*. They are not the focus of *WinP* and are only considered as an additional (not alternative) policy option in its conclusions. We will return to them later.

To date, international climate policy has been solely concerned with allowing more heat to escape to outer space. This is done by reducing the heat reradiated back to Earth’s surface by atmospheric greenhouse gases (GHGs), the most important of which are carbon dioxide (CO2) and methane (CH4). GHGs occur naturally and without them Earth would be some 33oC cooler. They are vital in maintaining the stable climate in which life as we know it has flourished. However, too much GHG can be both a major cause and consequence of global warming. Since the mid-eighteenth century, when industrialisation began, humanity has significantly increased the amount of GHGs in the atmosphere, principally by burning fossil fuels, although changes in land use and growth in livestock farming have also been major contributors. This increase has been so rapid that there is no equivalent in the geological record dating back hundreds of millions of years.

Atmospheric GHGs can be reduced either by emitting less of them (*mitigation*, *emissions reduction* or *abatement*), or by removing from the atmosphere those already emitted and still resident there. (*carbon dioxide removal (CDR)* or more broadly to include non-CO2 GHGs, *greenhouse gas removal (GGR)*). There are many technologies and changed environmental practices that could remove past emissions from the atmosphere. None of these is yet a credible method at the scale and speed likely to be necessary for an effective response to climate change.

Climate change policy revolves around a set of simple questions. These include, but are not limited to: What is a safe amount of warming? How much warming has already occurred? How much warming has yet to emerge from past GHG emissions? What is the relationship between, on the one hand, the speed and scale of future emissions reductions and GGR and, on the other, the speed at which surface temperature would stop increasing and begin to return to a safe level? What are the risks to humanity and the rest of life, if policy interventions are either too little or too late? If these risks are considered unacceptable, what additional measures could be adopted to improve the prospects of a safe and orderly outcome?

To help in answering these questions, scientists have developed two metrics of particular importance – climate sensitivity and climate response time. Climate sensitivity is defined in several ways; they all seek to measure the amount by which global average surface temperature would eventually rise in response to changes in the energy balance at TOA; this is referred to as the equilibrium temperature.

Climate sensitivity is conventionally defined as the warming from a doubling of atmospheric CO2, a metric known as Equilibrium Climate Sensitivity (ECS). However, because CO2 is not the only cause of warming, it is also measured in terms of the temperature change from a change of one unit of net energy flow across the boundary at TOA. The relationship between these two measures is explained below.

Climate response time is a measure of how long it would take to reach that equilibrium temperature following a change in the energy flows. It is also referred to as *emergence*. Mathematically it is referred to as *e-folding time*. This is the time it takes for about 63% of the latent change to emerge. To illustrate: if the total latent change is, say 10oC and the e-folding time is 100 years, the warming that would have emerged after 10, 50 and 100 years would be 0.9oC, 3.9oC and 6.3oC respectively. In the next 100 years, similar proportions of the remaining 3.7oC (10oC - 6.3oC) would emerge, so that after 200 years, all but 1.4oC of the original 10oC will have emerged. After 460 years all but 0.1oC of the 10oC would have emerged.

Two other terms need explaining, *radiative* *forcing*, often referred to simply as *forcing*, and *feedback*. First radiative forcing: when a body is in energy equilibrium with its surroundings, any energy lost is immediately replaced from outside so that it stays in the same state, neither warming nor cooling. If energy is prevented from escaping from the body, or the incoming energy were to increase, it will gradually warm up, but it doesn’t continue to warm indefinitely. As it warms, the rate at which it loses heat is naturally forced to increase until its energy losses again match the energy arriving from outside and equilibrium is restored[[4]](#footnote-4). However, when that happens the body will be warmer than it had been in its earlier equilibrium state. The flow of energy across the boundary between the body and its surroundings that causes the warming (or cooling if the changes allow more energy to escape or reduce the incoming energy), is referred to as the *radiative forcing*. If the body is getting warmer the forcing is positive, if cooler, then it is negative. Forcing is measured in W/m2 (or W m-2).

Climate *feedbacks* occur when a change in one climate quantity causes a change in a second, and the change in the second quantity ultimately leads to an additional change in the first. Negative feedback occurs when the initial change is weakened by the changes it causes; in positive feedback it is enhanced. Systems subject to negative feedbacks tend to remain in a steady state, whereas those subject to positive feedback get out of control and without external intervention, eventually collapse. The everyday example of negative feedback is a central heating thermostat, and for positive feedback it is the screeching from a loudspeaker when a microphone is placed in front of it. Climate feedbacks occur from many sources including, for example, changes in cloud and ice sheet cover, even the increasing atmospheric concentration of GHGs has feedbacks that increase those GHGs.

To understand the significance of *WinP*, the reader should bear in mind that the greater the climate sensitivity, the greater the future warming from past emissions, and the greater the response time, the more harm will be caused by that warming. For the period from 1750 to 2019, IPCC AR6 reports its best estimate for ECS to be 3oC (2 oC - 5oC) (AR6 FAQ 7.3) and effective radiative forcing (ERF) between 1750 and 2019 of 3.84 W/m2. *WinP’s* comparable measure of Earth System Sensitivity (ESS) is about 10oC. It is based on climate forcing of 8.25 W/m2 which includes certain feedbacks not included by IPCC. The corresponding climate sensitivity is 1.2oC per W/m2. IPCC AR6 reports a climate response time of the order of 10 to 20 years (AR6 Box TS.8 and Figure 4.39), whereas *WinP* puts it closer to a century. These higher values imply that the climate is currently in a considerably more perilous state than previously understood, and that current international policies are incapable of averting what may prove to be a widespread existential collapse for many species and ecosystems, including humanity. However, without diminishing the central message that the IPCC has grossly underestimated climate sensitivity and response time, care must be taken in comparing IPCC and *WinP* conclusions because, as explained below, *WinP*’s definitions include significant changes to those employed by IPCC.

The reader should also be aware that differences of opinion about the correct values for climate sensitivity and response time are in part due to the historical lack of the reliable observed data from which to determine them. The climate system is impenetrably complex, and methods do not exist to isolate all its variables to assess their precise impact on each other. This has resulted in all such estimates so far being based on climate models whose outputs cannot be fully corroborated with empirical data. While models provide valuable insights and may correlate well with some known historical data, the wide range in model outputs demonstrates the inherent dangers in treating their results as if they were observed facts. *WinP* addresses that problem by using newly acquired paleoclimate data that fills in many of the knowledge gaps, albeit not all them. Its approach is based on assumptions, that it justifies, that the dynamics of the climate system throughout the Cenozoic era, covering the last 66 million years can, with care, be applied to today’s climate conditions.

What follows is (mostly) an edited version of *WinP* recast for those with less technical climate knowledge than its authors’ intended audience. It also includes some additional comments intended to enable the reader to better grasp the significance of some of the issues raised.

**Climate sensitivity**

The climate sensitivity measures used by IPCC do not include feedbacks from ice sheet cover, vegetation and long-lived GHGs, other than CO2, all of which are deemed not to change on timescales of human interest. Thus, feedbacks are classed as ‘fast’ or ‘slow’ and only the fast feedbacks such as clouds, aerosols, water vapor, snow cover and sea ice, are included in ECS. Defined in this way, ECS becomes what, in reference to Einstein, *WinP* refers to as a *gedanken concept*, or thought experiment. It cannot be directly tested by empirical measurement because it would never be possible to measure the impact of the excluded elements; this can only be done by climate models. *WinP* seeks to overcome this limitation by reference to observed paleoclimate data.

*WinP* first undertakes a review of climate sensitivity and its development since 1979 when Charney1 calculated ECS to be 3oC ±1.5oC per W/m2, much the same value as had been estimated by Arrhenius in the nineteenth century and continues to be the mainstream value applied for policymaking. A detailed exploration is undertaken of several refinements in assessing ECS, and their respective limitations, by reference both to earlier research by Hansen, the lead author of *WinP*, and the IPCC Assessment Reports, to which Hansen has also been a significant contributor. The radiative forcing from a doubling of CO2 is widely agreed to be about 4 W/m2. If ECS is 3oC, this is equivalent to 0.75oC per W/m2.

If Earth were a perfect black body, a forcing of 4 W/m2 would increase surface temperature by 1.2oC to restore energy equilibrium at TOA. But Earth is not a perfect black body because feedbacks within the Earth system retain energy, forcing the temperature to rise even further to increase the heat escaping at TOA to restore equilibrium. This additional warming due to feedbacks is brought about by the increase they cause in radiative forcing. The gain in forcing is related to ECS as follows:

ECS = 1.2oC/(1-*g*)

Where *g* is the gain measured in W/m2 and ECS is in oC per W/m2.

An inescapable consequence of the arithmetic is that ECS is highly sensitive to uncertainty in *g.* This uncertainty emerges from the difficulty of measuring the feedback gain. For example, if the gain were 0.7 W/m2, meaning that 70% of the increase in equilibrium temperature comes from feedbacks and only 30% directly from CO2, ECS would be 4oC. If, however, *g* is 14% higher at 0.8, ECS increases by more than 50% to 6oC. Positive feedbacks in the climate system cause their influence on ECS to grow hyperbolically.

*WinP* argues that ECS is about 4oC rather than 3oC as estimated by Charney and refined by the IPCC. *WinP* notes that from models alone, it is not possible to corroborate either its 4oC figure or refute the other*s’* 3oC. Its mission is to narrow these uncertainties. After examining several alternative attempts to determine ECS and illustrating inconsistencies with each, *WinP* concludes that by comparing glacial and interglacial equilibrium climate states for which reliable temperature and atmospheric composition data are now available, the change of atmospheric and surface forcings can be more accurately determined.

Looking first at model results since industrialisation began in 1750, most assessments of ECS, including those from IPCC and Hansen, converge on a climate forcing of about 4W/m2 ± 0.4 W/m2. This includes all the fast feedbacks, not just the forcing from changes in atmospheric CO2. Given that the forcing from a doubling of CO2 is also about 4 W/m2, it is apparent, that when all the fast feedbacks are considered, human activity has now produced a climate forcing equivalent to a doubling of CO2 even though CO2 alone has only increased by 50% from 278 to 420ppm.

Antarctic ice cores provide detailed and accurate data for the past 800,000 years. There were several ice-age cycles during this period. These are referred to as glacial (cold) to inter-glacial (warm) transitions, each one typically lasting about 100,000 years. *WinP* concludes that the most recent interglacial, the Holocene in which we are still living, is unusual because there is evidence of early human impacts on the atmosphere. Accordingly, they choose a time 7kyBP[[5]](#footnote-5), prior to human interference in the climate system, as their base line for the purpose of comparing climate states.

Recent advances have shown that surface temperatures in the distant past can be more accurately assessed by analysis of changes in an isotope of oxygen present in the deep ocean. This suggests 7oC temperature difference between the Last Glacial Maximum (LGM – 21-19 kyBP) and the mid-point of the current inter-glacial 7kyBP. From this data, *WinP* estimates the GHG forcing between the LGM and mid-Holocene, a period of some 13,000 years, to have been 2.25 W/m2 of which 77% came from CO2. During this period there were no human aerosols and those in the atmosphere could only have come from natural sources[[6]](#footnote-6). These do not need to be considered separately as they are natural feedbacks included in the climate response.

*WinP’s* assessment of forcing from changes in surface reflectivity (albedo) in this 13,000-year period is 3.5 ± 1 W/m2, which when added to the 2.25 W/m2 from changes in GHGs, yields the total forcing of about 5.75 W/m2 that delivered the 7oC temperature difference. This is 1.2oC per W/m2 (7/5.75) and is a key statistic central to the later conclusions about warming in the pipeline.

Before leaving this topic, *WinP* provides some evidence that suggests that for the period of practical interest to today’s policymakers, ECS is largely independent of variability in the climate state. In the formula above, uncertainty in the value of the feedback gain (*g*), arises from the practical problem of measuring it accurately, rather than from it being highly sensitive to changes in the state of the climate. Accordingly, the 1.2oC per W/m2 can be assumed to apply to current and immediately foreseeable circumstances.

**Warming the pipeline**

*Current forcing*

Having established ECS of 1.2oC per W/m2, *WinP* turns its attention to the incremental forcing since 1750. IPCC AR6 reports GHG forcing as 3.84 W/m2 from 1750 to 2019 (AR6 7.3.5.2). *WinP* provides a technical assessment of several refinements in the definition of forcing. This topic has been extensively covered by Hansen2, and his and others’ contributions inform a lengthy discussion of this topic in IPCC AR5. The extreme complexity of atmospheric chemistry and physics is such that there is no single correct measure of forcing that applies uniformly across all forcing agents and in all climate states. Accordingly, some judgement is necessary in selecting measures of radiative forcing that best serve the analysis in hand. For the purposes of assessing warming in the pipeline, *WinP* concludes that the IPCC value should be increased by 0.30 W/m2 to account for a small amount of forcing that is excluded from the metric used by IPCC. This is a material increase of almost 10% to 4.14 W/m2 and is part of the core message of this paper that the IPCC models are insufficiently sensitive to real world forcing.

Further adjustments are made to rebase the calculation from 1750 to 7kyBP, to eliminate all human impact on the forcing, and to bring it forward to 2021 from the IPCC’s 2019. This increases the forcing to 4.6 W/m2 ignoring the slow feedbacks excluded from the conventional ECS assessment used by IPCC. *WinP* argues that the true forcing must also include these slow feedbacks from changes in ice sheet cover and non-CO2 GHGs and it uses new empirical data from the Cenozoic to assess their impact.

*Including slow feedbacks*

*WinP* notes that a fundamental difference between the paleoclimate record and the last 250 years is the rate at which GHG emissions have been increased by human activity. So-called ‘slow’ feedbacks are determined by the chemical and physical processes that provoke them and when those processes are speeded up, the feedbacks also speed up. In assessing current climate change, these slow feedbacks are now significant on human timescales and a sound assessment of climate responses to increased forcing requires their inclusion.

The novel feature of this study is the introduction of new empirical data from the Cenozoic and its capacity to provide more accurate assessments of climate dynamics over a 66-million-year period with the specific purpose of quantifying the forcing from slow feedbacks. The three main conclusions from that data relevant to today’s concerns about climate sensitivity are first that the slow feedback from changes in ice cover has been relatively constant at 2 W/m2 throughout this period; second, that non-CO2 forcing has been about 25% of the combined forcing from GHGs and ice sheet cover; and third, that today’s man-made forcing is of the same order as the forcing that some 60MyBP caused surface temperature to approach 35oC, more than 20oC warmer than today.

Applying this new data to the human forcing of 4.6 W/m2 generates a total forcing for the period from 7kyBP to 2021 of 8.25 W/m2 ((4.6 + 2) x 1.25). Applying the ECS of 1.2 W/m2 to this, the equilibrium surface temperature is seen to be 10oC (8.25/1.2). Caution is needed when contrasting this with the IPCC’s figure of 3oC.

First, the 10oC increase in surface temperature has an e-folding time of about 100 years. This implies that it would take more than 400 years to fully emerge and in the first century, the increase would only be 6.3oC. By 2100 it would be about 5oC. This is both good and bad news. The extended period gives the warming more opportunity to warm the surface and reduce ice cover, which will increase the harm from the warming. On the other hand, it will happen more slowly giving more time to react with effective policies to reverse the warming trend.

Second, the 10oC assumes that the man-made forcing remains at its current level, which in turn implies that atmospheric GHGs and Earth’s albedo remain at their current levels. If they were to continue their current trends, even at a slower rate, the future temperature increase would be even higher, and conversely, if through emissions abatement and GHG removal the forcing were to subside, the temperature increase would be somewhat less. However, the greater warming in the pipeline and the much longer response time mean that it is now implausible that any feasible reduction in emissions and GGR in the coming decades will be sufficient to prevent warming passing critical thresholds that are likely to unleash cascading irreversible climate changes. These are referred to as tipping points.

*WinP* does not address the point directly, but its conclusion that IPCC has underestimated ECS appears to undermine the IPCC’s argument that temperature would cease increasing within a few decades after reaching net zero. It is to be hoped that this implication of *WinP’s* conclusions will be explored in detail.

A third important consideration is the role of human generated aerosols. How these are managed will have a material bearing on future warming. This is explored below.

**Climate response time**

From a comparison of the 2014 and 2020 versions of the GISS climate model, *WinP* identifies a significant difference in the response time for EEI and surface temperature. It concludes that the rapid response of EEI with an e-folding time of about 5 years, and the much slower e-folding time of about century for surface temperature, indicate the existence of *ultrafast* feedbacks. In the absence of credible alternatives, they ascribe these to feedbacks from changes in cloud cover. Clouds respond not only to changes in temperature but also changes in radiative forcing through effects on cloud particles, cloud cover, cloud albedo and precipitation. The details of these ultrafast feedbacks are not yet well understood but their existence and effects are evident from climate models.

A consequence of the fast response time for EEI and the much slower response for surface temperature, is that the forcing necessary to rebalance the surface temperature is greater than that required to rebalance the EEI. This presents a significant additional challenge because the difficulty in finding any additional reduction in climate forcing of even a few tenths of a W/m2 is substantial.

**Aerosols**

Aerosols are particulate matter suspended in the atmosphere most of which back-scatter sunlight to outer space. In doing so they increase Earth’s albedo and therefore have a cooling effect. The burning of carbon fuels emits large amounts of aerosols. It is estimated that the absence of any warming prior to the industrial era, despite humanity having been burning biomass since the dawn of time, is that it was offset by the aerosols that accompanied the GHGs, and the CO2 drawn down by plant photosynthesis. With the advent of the industrial era and the rapid increase in the burning of fossil fuels, the balance between emissions of GHGs and aerosols shifted so that by about 1970, the positive forcing from the GHG emissions exceeded the negative forcing of the aerosols, an excess that has continued to grow.

*WinP* notes that applying its ECS of 1.2oC per W/m2 in its formula for surface temperature produces 1.5oC more warming than observational evidence supports. They ascribe this difference mostly to negative forcing from aerosols and minimally to changes in albedo from ice sheet cover. The IPCC reports the negative forcing of aerosols to be about 1 W/m2, whereas that from changes in ice sheet cover is about 0.1 W/m2. A forcing of 1 W/m2 with an ECS of 1.2oC per W/m2 produces a temperature difference of 1.2oC, sufficient to account for most of the observed 1.5oC anomaly.

*WinP* explains what Hansen has previously referred to as a Faustian bargain, in which aerosols deliver immediate benefits by limiting warming, but as they decline, the warming they have masked returns. Evidence for this has emerged within the last 20 years as a result of global shipping switching to low sulphur bunker fuels for public health reasons, to reduce the atmospheric pollution responsible for undermining the health of thousands of people around the globe and consigning many of them to premature and unpleasant deaths. Unlike emissions of CO2 which linger in the atmosphere for centuries, aerosols fall out of the atmosphere within days and weeks in response to local weather conditions, in particular rain. The decline in their cooling effect has been registered in the acceleration of surface warming over the last decade and is likely to continue as result of both a trend towards cleaner fossil fuels and the switch to renewables. Warming is therefore expected to increase more rapidly in the next twenty years than it did in the last twenty years.

If the current negative forcing from aerosols were maintained, *WinP’s* 10oC equilibrium temperature would be reduced to about 7oC. However, it is also noted that while the broad trends are clear, there is uncertainty as to the detail because of the paucity of data about aerosols and their complex interactions with other climate variables, especially with clouds.

**Conclusion**

In the concluding section of *WinP*, Hansen, as lead author, summarises the scientific content of the paper, including reference to current knowledge gaps, and sets it in a climate change policy context.

There are three main scientific inferences from this research. First, assuming atmospheric concentrations of GHGs remain as they are today, more than 80% of the warming from past GHG emissions has yet to emerge. This percentage will increase if GHG concentrations are allowed to continue increasing, even if more slowly than in the recent past, and will decrease in response to successful efforts to reduce those concentrations. Second, warming will continue to accelerate as the cooling effect from man-made aerosol pollution declines. Third, the time it takes for surface temperature to change in response to changes in atmospheric GHGs, is four to five times longer than represented by the IPCC. This will allow more time for interventions directed at reducing the damage from further warming, but will also increase that damage if decisive action is not taken.

Having examined the science of climate response time, Hansen discusses the time available for decisive action ‘before we pass the point of no return, the point where major climate impacts are locked in, beyond our ability to control’ - a reference to tipping points. He notes that present levels of GHGs are 70% of what they were 50 MyBP when surface temperature was 13oC hotter than today, and already far above the level needed to melt Antarctica. He is not suggesting that there is any imminent danger of Antarctica becoming deglaciated, but he is recognising that once that process is in train, it is likely to be beyond human capacity to stop. Whether Hansen is right that this is policy-significant today, depends upon one’s moral relationship to the distant future.

More urgently, Hansen also points to changes in the Arctic and to the Greenland ice sheet that could cause sea level rise of several meters within little more than a century. This would have major climate, ecosystem and socio-economic impacts as it would cause widespread local climate changes, particularly through changes to Atlantic surface and deep ocean currents.

Hansen’s policy exhortations are threefold: a) emissions must be reduced and for this he advocates global carbon pricing; b) there must be greater international collaboration on climate policy; and c) it is now necessary directly to intervene to reduce EEI by reducing sunlight reaching Earth’s surface. The first two have been central to orthodox climate policy since the 1980s to little climate effect. Despite Hansen’s pleas, it is unclear what might provoke a significant change in either of these policy domains in the near future. The research presented in this paper may bring greater clarity to the science, but it does not introduce any new policy imperatives that were not apparent several decades ago. The danger that Hansen tilts at is that by the time the international community does gird its loins to act decisively, the task of maintaining a stable climate will have grown beyond our combined capacities.

His third policy, to engage in albedo enhancement (AE), is a radical departure and one that was discussed in AR6 and dismissed as being too risky. The IPCC’s treatment of this subject was trivial in that it gave no consideration to the risks of not deploying AE. Hansen is now arguing that those risks outweigh those from the properly researched and trialled deployment of AE. He is also, by implication, making the point that AE is now necessary, rather than being merely an alternative or adjunct. As a necessary policy response, concerns about it reducing efforts to decarbonise the global economy, the so-called moral hazard argument, are rendered void; when both are necessary it is incompetent and reckless to allow one to displace the other. Moreover, if both are necessary, success in one will be undone by failure to attend to the other.

A central element of the argument made by Hansen for AE rests on *WinP’s* conclusions about climate response time. With an e-folding time of a century, efforts to reduce surface temperature by reducing emissions and GGR alone will not be effective sufficiently soon to avert the risks from the irreversible climate impacts to which he refers. AE will act rapidly in reducing surface temperature and this is now the urgent need to avoid the risks of triggering tipping points. From a risk management perspective, the policy response to tipping points should recognise them as truly existential threats, and as such the policy goal must be to reduce their risk of occurrence to almost zero. This requires the climate emergency to be treated as such, rather than being, as it is at present, an emergency on name only.

*WinP* is currently in peer review and it may be subject to some revisions as part of that process. Concerns may be raised about its reliance on one climate model. However, the main conclusions from this paper are unlikely to be materially affected by comparison with other models because they arise more from its reliance on new improved paleoclimate data as a more solid basis for analysis. Moreover, more models do not necessarily imply greater accuracy as it is not statistically sound practice to average climate model results. They commonly produce results across a wide range, and each is as likely to be the most accurate as any other. *WinP* identifies several knowledge gaps in respect of which it has made certain assumptions. Reviewers may question these or argue that they introduce higher levels of uncertainty than assessed in *WinP.* Nevertheless, until a peer reviewed version is published in a leading academic journal, *WinP* should be treated with care. Nevertheless, since the 1980s Hansen has routinely been ahead of the curve on climate change, the great likelihood is that he still is.

**References**

1. Charney, J. *Carbon Dioxide and Climate: A Scientific Assessment*. (National Academies Press, 1979). doi:10.17226/12181.

2. Hansen, J. Efficacy of climate forcings. *J. Geophys. Res.* **110**, D18104 (2005).

1. There are other sources of energy, some from cosmic sources and others released by seismic activity from within Earth itself. These are not significant in planetary warming and cooling. [↑](#footnote-ref-1)
2. There may also be ways to stop surface temperature rising by transferring heat to the deep oceans. While theoretically possible, the engineering, cost and timing challenges render this option less attractive than the alternatives. This is also a temporary fix as that heat will re-emerge over several centuries. [↑](#footnote-ref-2)
3. *Albedo* is the technical term for the reflectivity of a surface – a perfect mirror that reflects all the light that falls on it has an albedo of 1, and a perfect black surface that absorbs all the light that falls on it has an albedo of 0. [↑](#footnote-ref-3)
4. Newton’s Law of Cooling is a law of physics that states that the rate of cooling is proportional to the difference in temperature between a body and its environment. It follows that if the body warms and its environment doesn’t, the body will cool faster as the temperature difference increases. If the body is allowed to cool, the rate of cooling will decrease, as the temperature difference decreases. [↑](#footnote-ref-4)
5. The distant past is referred to in years before present (yBP) adding k or M to indicate thousands and millions respectively. [↑](#footnote-ref-5)
6. Natural aerosols come from many sources including: volatile organic compounds produced by trees, sea salt produced by wind and waves, black and organic carbon produced by forest and grass fires, dust produced by wind and drought, and marine biologic dimethyl sulphide and its secondary aerosol products, all varying geographically and in response to climate change. [↑](#footnote-ref-6)