"A Miracle Will Occur" Is Not Sensible Climate Policy

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The COP28 Chairman and the United Nations Secretary General say that the goal to keep global warming below 1.5°C is alive, albeit barely, implying that the looser goal of the 2015 Paris Agreement (to keep warming well below 2°C) is still viable. We find that even the 2°C goal is dead if policy is limited to emission reductions and plausible CO_2 removal. IPCC (the Intergovernmental Panel on Climate Change, which advises the UN) has understated global warming in the pipeline and understated fossil fuel emissions in the pipeline via lack of realism in the Integrated Assessment Models that IPCC uses for climate projections. Wishful thinking as a policy approach must be replaced by transparent climate analysis, knowledge of the forcings that drive climate change, and realistic assessment of policy options. The next several years provide a narrow window of time to define actions that could still achieve a bright future for today's young people. We owe young people the knowledge and the tools to continually assess the situation and devise and adjust the course of action.

Our approach to analysis of global climate change, as described in *Global Warming in the Pipeline*,[1] puts comparable emphasis on (1) Earth's paleoclimate history, (2) global climate models (GCMs), (3) modern observations of climate processes and climate change. One purpose of the *Pipeline* paper was to distinguish between this approach and that of IPCC, which puts principal emphasis on GCMs. GCMs are an essential tool, but the models must be consistent with Earth's history and the projections of future climate must employ plausible scenarios for energy use and for the climate forcings that drive climate change.

Policy implications of climate science can be grasped from a basic understanding of the human-made forcings that are driving Earth's climate away from the relatively stable climate of the Holocene (approximately the past 10,000 years). Our task is to provide understandable quantification of climate forcings and changes that will be needed to maintain a hospitable climate. Concerned public, including policymakers, must learn to appreciate basic graphs that summarize real-world data, because these must provide the basis for policy discussion.

1. CLIMATE SCIENCE

There are two major climate forcings: human-made greenhouse gases (GHGs) and aerosols (fine airborne particles). GHGs reduce Earth's thermal (heat) radiation to space and are the main cause of global warming. Aerosols reflect sunlight to space, mainly via their effect as condensation nuclei for clouds; more nuclei lead to smaller cloud drops and brighter, longer-lived, clouds. Aerosols thus cause a global cooling that partially offsets GHG warming.

Greenhouse Gases. We begin with a graph that describes continuing growth of GHG climate forcing. This graph provides a proper comparison of the relative importance of different gases in driving global warming. Fig. 1 shows the annual change of the GHG climate forcing, which is increasing about 0.05 W/m^2 per year, a rate that has increased since the early 1990s. Maximum growth rate occurred about 1980, as chlorofluorocarbons (CFCs) were increasing rapidly until being curtailed by the Montreal Protocol.[2] We show the 5-year running mean in Fig. 1 because the "noise" in the annual mean hides trends that we wish to understand.[3] The 2022 point in the graph is a 1-year mean and the 2021 point is a 3-year mean; thus these are provisional and will change as later data are added. The GHG climate forcing today (the sum of annual increments from 1750 through 2023) is 4.2 W/m^2. Our calculated forcing agrees

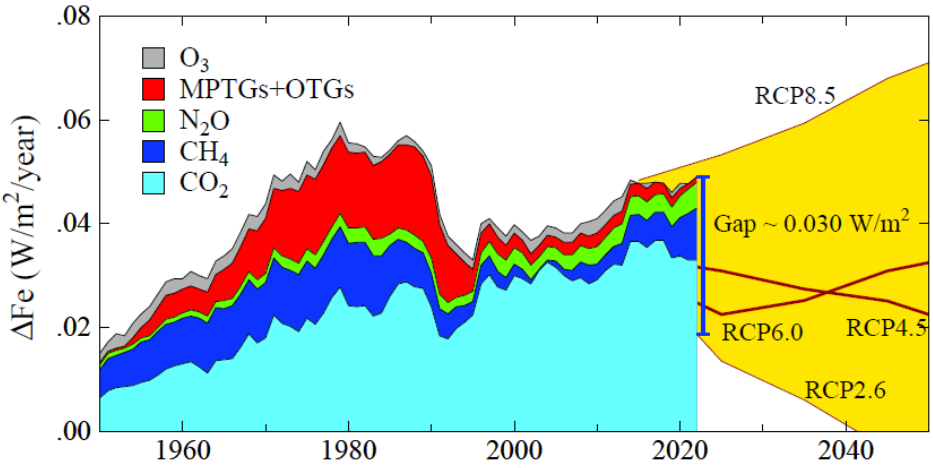

Fig. 1. Annual growth of climate forcing by GHGs[4] including the part of O_3 forcing not included in the CH_4 forcing.[1] MPTG and OTG are Montreal Protocol and Other Trace Gases.

closely with the IPCC[5] calculated forcing. This is a huge climate forcing,[6] slightly exceeding the ~ 4 W/m^2 forcing for doubled CO_2 ($2\times CO_2$). If a forcing this large or larger is left in place indefinitely, it will transform the planet.

IPCC's best estimate for equilibrium climate sensitivity (ECS) is 3°C, but we show from paleoclimate data that ECS = 4.8°C ± 1.2°C, which excludes 3°C with > 99% certainty.[1] ECS includes only "fast" feedbacks that occur in response to climate change, the most important being changes of atmospheric water vapor, clouds, and sea ice.; it excludes "slow" feedbacks such as change of ice sheet size and methane (CH_4) released from melting permafrost or methane hydrates. Nevertheless, ECS is the proper sensitivity to employ in analysis of human-made climate change to date, because the ice sheets have not yet changed much in size and any slow feedback release of GHGs is accounted for (treated as a climate forcing) in GCM simulations based on measured GHG changes.

Real-world GHG forcing is also compared in Fig. 1 with scenarios defined a decade ago and used by IPCC. Note that the real world is closer to the extreme scenario RCP8.5 than it is to scenario RCP2.6. [Numerals after RCP are the scenario's GHG forcing in year 2100.] RCP2.6 was defined such as to provide a 66 percent chance of keeping global warming under 2°C. Scenario RCP2.6 is a product of an Integrated Assessment Model (IAM). Assumptions in IAMs can yield implausible results. RCP2.6, e.g., assumes deployment of a vast array of powerplants that burn biofuels, capture the CO_2 emissions, and permanently bury the CO_2 (BECCS = bioenergy with carbon capture and storage). BECCS on such a massive scale would be nature-ravaging and food-security-threatening.[7] In *Pipeline* and elsewhere we note that the gap between RCP2.6 and reality could be closed via direct-air CCS, but the annual cost with present CCS is $3.4-7 trillion and growing; also, transporting and storing that much CO_2 underground would likely generate public opposition.

Additional concerns about unrealism in IAMs are discussed below. However, note first that global warming through 2022 is only ~ 1.2°C, much less than expected equilibrium warming. There are two reasons for the "small" magnitude of observed warming. First, the ocean's great thermal inertia slows the response to climate forcing. [Even after 100 years the expected surface temperature response to a forcing is only about 60 percent (Fig. 4, *Pipeline*).] Second, human-made aerosol forcing causes cooling that partly offsets GHG warming. Thus, we must discuss aerosol climate forcing before we can address IAMs in more detail.

Aerosol climate forcing and cloud feedbacks. Measurement of aerosol climate forcing requires precise global monitoring of aerosol and cloud particle microphysics,[8] which has not

been achieved. Thus, aerosol forcing has *de facto* been a free parameter, which allows any ECS to match observed global warming of the past century. A climate model with high ECS must use large aerosol cooling to match observed warming. There is nothing nefarious here – the shotgun marriage of climate sensitivity and aerosol forcing is due to the *status quo* of scientific knowledge of aerosol forcing.

Given the absence of direct measurement of aerosol forcing, we obtain useful indications about aerosol forcing from both paleoclimate and from modern observations of a remarkable, inadvertent, global aerosol "experiment" now playing out. Let's start with the paleoclimate.

In *Pipeline*, we describe resolution of a 40-year-old mystery about global temperature in the last glacial maximum (LGM).[9] The answer, noted above, is that the LGM at the time of peak cooling (18-21 kyBP, kiloyears before present) was 7°C ± 1°C colder than the Holocene. This large LGM cooling leads to ECS = 4.8°C ± 1.2°C for $2\times CO_2$. If LGM cooling were only 3.5°C, as was widely assumed 40 years ago, ECS would be only ~ 2.4°C for $2\times CO_2$. GCMs alone could never have resolved this mystery, because GCM results depend on all climate feedbacks, which are still poorly understood. In contrast, real-world climate change between LGM and Holocene equilibria exactly includes all real-world feedbacks, thus permitting precise evaluation of ECS once the LGM and Holocene climate states are well-defined.

Given that aerosol climate forcing occurs mainly via alteration of cloud properties, we must consider cloud feedbacks at the same time as aerosol forcing. Cloud feedbacks do not make it impossible to evaluate aerosol forcing from observations, but they make the task difficult. Cloud feedbacks cause GCMs to yield a wide range of ECS. GCMs with fixed clouds, i.e., with a neutral cloud feedback, yield ECS ~ 2.4°C for $2\times CO_2$. However, GCMs that yield a small decrease of cloud cover as Earth warms can readily yield an ECS of 4.8°C or greater. In recent years, a number of GCMs have yielded ECS ~ 4-6°C for $2\times CO_2$, especially among GCM groups that attempt to model complex cloud microphysics. With a hint of denigration, these high-ECS models have been described as the "wolf-pack," to contrast them with the "pack," the mainstream climate models with ECS nearer 3°C. IPCC, in taking 3°C as their best estimate for ECS, in effect, endorses "mainstream" climate models. At a webinar[10] on our *Pipeline* paper, George Tselioudis showed figures of Zelinka *et al*.[11] and Jiang *et al.*[12] revealing that the high sensitivity models are in much better agreement with satellite observations of seasonal and latitudinal cloud changes. Cloud modeling is primitive, but these models suggest that cloud feedbacks are a major cause of high climate sensitivity. One implication is that interpretation of satellite observations of Earth's energy balance must distinguish between cloud feedbacks and aerosol forcing of cloud changes.

Separating cloud feedbacks from aerosol induced cloud changes might be a Sisyphean task, if not for the "experiment" initiated by the International Maritime Organization (IMO) when it placed a constraint on sulfur content of ship fuels beginning January 2015 and tightened it in January 2020.[13] This experiment, although the change occurs in two steps, has a reasonably sharp beginning[14] and ship traffic has a known geographical distribution (Fig. 20 in *Pipeline*, from Jin *et al*.[15]). Prior to the IMO regulations, ships were the main source of sulfur aerosols in the North Atlantic and North Pacific regions. In contrast, the largest cloud feedback is probably in the southern half of the Southern Hemisphere (south of 30°S).[11]

The IMO experiment and implications. The most informative diagnostic for interpretation of the IMO aerosol experiment is change of absorbed solar radiation. Earth radiation budget data are acquired by CERES[16] (Clouds and Earth's Radiant Energy System) launched early this century. CERES measures solar radiation reflected by Earth and thermal (heat) radiation emitted by Earth. Reflected solar radiation declines coincident with imposition of the IMO sulfur rules. We graph the increase of absorbed solar radiation (Fig. 2); it reveals a decrease

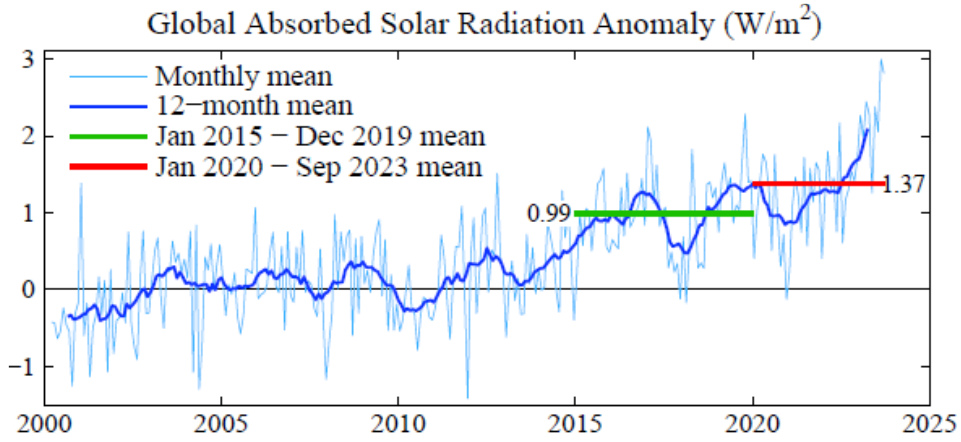

Fig. 2. Global absorbed solar radiation (W/m^2) relative to mean of the first 120 months of CERES data. CERES data are available at http://ceres.larc.nasa.gov/

of Earth' albedo (reflectivity) of 0.4% (1.37/340).[17] This reduced albedo is a BFD (a big deal).[10] It is equivalent to a sudden increase of atmospheric CO_2 from 420 ppm to 525 ppm.

This large change of Earth's albedo accelerates global warming. We will infer that most of the increased absorption of solar energy following the IMO rule change is aerosol forcing. This added forcing also spurs "fast" feedbacks, which come into play not in immediate and direct response to the forcing, but in response to global temperature change, which lags the forcing.

We estimate the net effect of the aerosol forcing from the climate response function (Fig. 3).[1] Warming depends little on ECS in the first few years after a forcing is introduced; early warming is ~ 1°C for 2×CO_2, thus ~ 0.25°C for 1 W/m^2 forcing. Fast feedbacks amplify the warming by a factor 1.5-2 by year 10 after the forcing is imposed (2015 and 2020 forcings have now existed 9 and 4 years). The fast feedbacks are water vapor, clouds and sea ice. Cloud and sea ice feedbacks operate by reducing Earth's albedo, i.e., by increasing absorbed solar radiation. Recent increase of absorbed solar radiation, reaching 2 W/m^2 on 12-month running mean (Fig. 2), in part reflects growing fast feedbacks, but it is consistent with an increase of aerosol forcing of the order of 1 W/m^2. Increased absorption is especially large in the North Pacific and North Atlantic (*Pipeline* Fig. 22). This increased regional absorption of solar energy and doubling of Earth's energy imbalance are likely to affect Arctic sea ice. Thus, we expect Arctic sea ice cover to soon fall below the 2012 minimum.

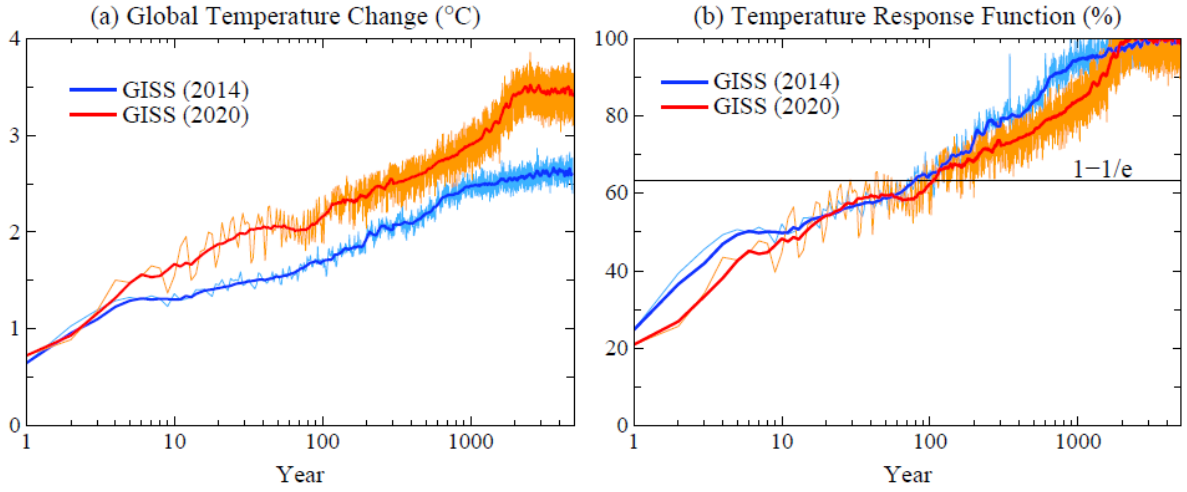

Fig. 3. (a) Global surface temperature response to CO_2 doubling and (b) normalized response function (% of final change). GISS 2014 and 2020 models have ECS == 2.7°C and 3.5°C.

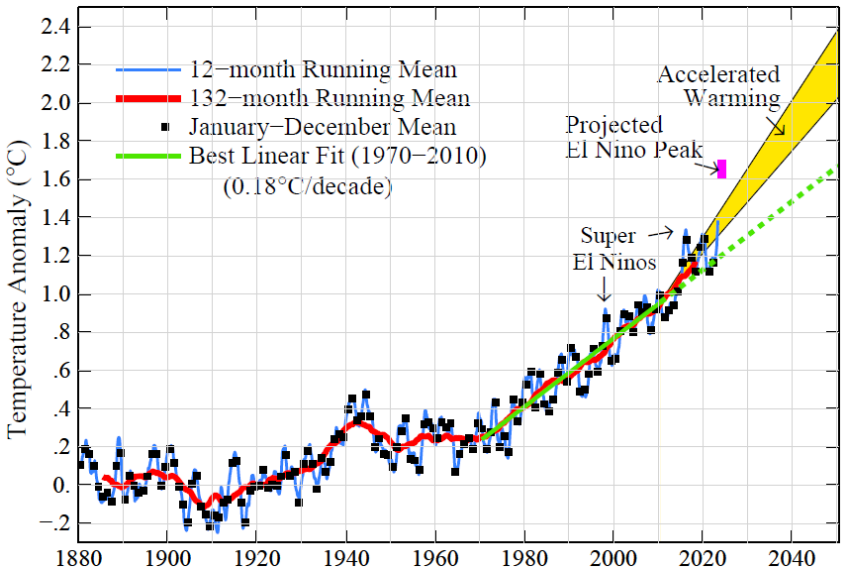

Fig. 4. Global temperature relative to 1880-1920 based on the GISS analysis.[18,19]

Accelerated global warming. We projected that decreased aerosols will increase the global warming rate, which was 0.18°C per decade in 1970-2010, by 50-100 percent, i.e., to 0.27 to 0.36°C per decade (Fig. 4).[1] Natural climate variability, due mainly to El Nino/La Nina, makes it difficult to measure change, but Fig. 5 provides insight. Deviations of global warming from its post- 1970 trend are well correlated with Nino3.4, despite disruptions such as global cooling after the 1991 Pinatubo volcanic eruption. Fig. 5 reveals recent excess global warming of ~ 0.2°C, consistent with most of the 1 W/m^2 absorbed solar radiation anomaly being aerosol forcing (the remainder presumably being fast feedbacks).

Our *Pipeline* projection of peak warming 1.6-1.7°C in mid-2024 is based on the observed doubling of Earth's energy imbalance. An alternative derivation,[20] based on aerosol forcing of 1 W/m^2 produces 0.3-0.4°C global warming by now (Fig. 3). With El Nino raising global temperature 0.1-0.2°C above the trend line and aerosol forcing adding 0.3-0.4°C to global warming, we would project peak 12-month-mean warming 0.4-0.6°C above the trend line in May 2024, thus including the possibility of warming slightly above the 1.6-1.7°C range estimated in *Pipeline* (pink region, Fig. 4). Regardless, if global warming exceeds the 1.6°C level, it will provide strong confirmation of global warming acceleration.

Decline of global temperature after the El Nino should be limited as "fast" feedbacks come into play more. Recent rise of the absorbed solar radiation 12-month running-mean (Fig. 2) is likely due to continued growth of cloud and sea ice feedbacks as well as the current solar cycle maximum (see below). Amplifying cloud feedback grows in proportion to temperature

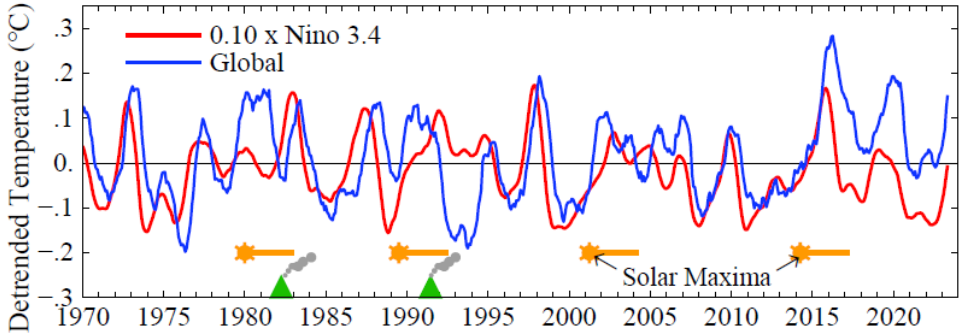

Fig. 5. Detrended global and Nino3.4 12-month running-mean temperatures; the trend subtracted from the temperature records is based on the period 1970-2010.

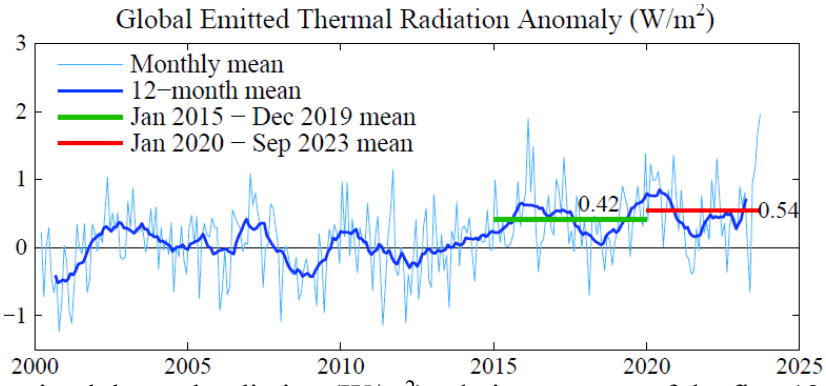

Fig. 6. Global emitted thermal radiation (W/m^2) relative to mean of the first 120 months of CERES data. CERES data are available at https://ceres.larc.nasa.gov/data/

rise, which is especially delayed in the Southern Hemisphere by the vast ocean. Increase of Earth's energy imbalance in the past decade speeds ocean warming and growth of the cloud feedback. Thus, the long-anticipated decrease of Southern Hemisphere sea ice, which began this year, will increase absorbed solar radiation and tend to limit global temperature decline.

Cause of current extreme global temperatures. Several ideas are eliminated by Earth's radiation budget data. Water vapor from the Hunga Tonga volcanic eruption in early 2022 and the moderate increase of the GHG growth rate in recent years (Fig. 1) have a warming effect, but they do so by decreasing thermal radiation to space. As Fig. 6 shows, infrared radiation to space has increased. The energy source driving extreme warming, instead, is a large increase (1.37 W/m^2) of absorbed solar radiation (Fig. 2). Increased emission to space (0.54 W/m^2) is less than half of the increased solar radiation absorption. This is the expected portion (Fig. 3) of the 1.37 W/m^2 "forcing" that appears as "realized warming" in less than 10 years. The remaining portion adds to Earth's energy imbalance (EEI), almost doubling the pre-2015 imbalance (Fig. 7). Increased EEI is the proximate drive of global warming acceleration.

Solar irradiance is near a maximum of the current solar cycle. Thus, the Sun adds a bit to recent high absorbed radiation (Fig. 2), but the full amplitude of the solar cycle is only about 0.2 W/m^2 (Fig. 7 of "Acceleration" communication[21]). Solar radiance declined in 2015-2020 when absorbed solar radiation rose rapidly, so solar variability is not the cause of accelerated global warming and it is only a minor contributor to current extreme global temperatures.

The current El Nino strengthened in recent weeks as a burst of westerly winds in the mid-Pacific equatorial region pushed warmer West Pacific surface water toward South America,[22] putting this El Nino in the "super El Nino" class of the 1997-98 and 2015-16 El Ninos as measured by the Nino3.4 index. The El Nino causes the steep rise of global temperature, but,

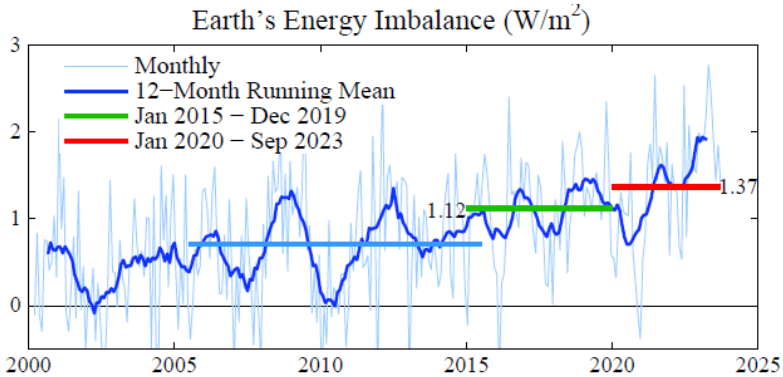

Fig. 7. 12-month running-mean of Earth's energy imbalance from CERES satellite data normalized to 0.71 W/m^2 mean for July 2005 – June 2015 (blue bar) from in situ data.

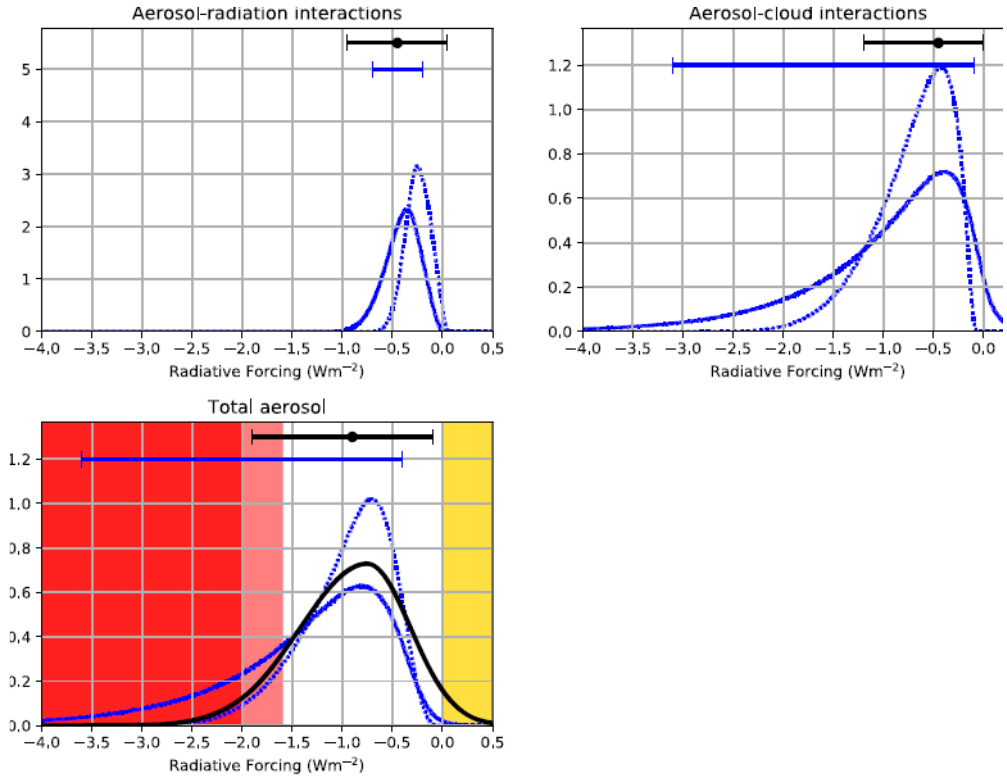

Fig. 8. Probability distribution function of effective aerosol forcing (solid lines) from IPCC AR5 report[23] (black) and Bellouin *et al*.[24] review (blue), from which these graphs are taken.

as shown by Fig. 5, additional post-2015 warming (coinciding with increased absorption of solar radiation, Fig. 2) makes the current global temperature unusually extreme.

Implications of global warming acceleration. Accelerated global warming will cause the 12-month running-mean global temperature to exceed 1.5°C within the next few months and reach a level far above 1.5C by May 2024. Global temperature should fall back below 1.5C with the next La Nina, but the decline likely will be limited and the El Nino/La Nina mean of 1.5°C will have been reached. Subsequently, global temperature will go even higher; that's assured by Earth's huge energy imbalance, which makes it unnecessary to wait a decade to declare that the 1.5°C limit has been breached.

We conclude that the increase of aerosol forcing since 2015 is of the order of 1 W/m^2, i.e., O(1 W/m^2). The continued rise of absorbed solar radiation is caused by growth of cloud and sea ice fast feedbacks, which rise in proportion to the accelerated global warming. Some studies, e.g., Diamond,[25] suggest that the global IMO-induced aerosol forcing is only O(0.1 W/m^2). Such a small aerosol-cloud forcing would be consistent with the IPCC best estimate for the total indirect (aerosol-cloud) forcing of only ~ 0.5 W/m^2 (Fig. 8). However, the observed response to the IMO "experiment" rules out such small estimates for the aerosol-cloud forcing. On the contrary, we find[1] that a single aerosol type (sulfate from ships) yields a forcing at least that large, that preindustrial humanity was already producing an additional aerosol forcing of at least 0.5 W/m^2 from wood and biomass fuel burning that continues today,[1] and thus that the peak human-made aerosol forcing is at least ~2 W/m^2.

A comprehensive review by Bellouin *et al*. reveals how IPCC was led to their unrealistically small aerosol forcing, as summarized in Fig. 8. Review of aerosol physics by Bellouin yields a range of estimated aerosol forcing as large as 3.6 W/m^2 (blue bars in Fig. 8), but forcing exceeding 1.6 W/m^2 (red region in Fig. 8) was ruled out because greater aerosol forcing and "mainstream" climate sensitivity would not yield global warming as large as observed. The

aerosol forcing that IPCC defines as highest probability is that which yields best agreement with mainstream GCMs. IPCC describes this substitute for measurement of aerosol forcing as an "emergent constraint" on ECS, a sophisticated pseudonym for the artifice. However, given the larger ECS dictated by real-world paleoclimate data (4.8°C±1.2°C for $2\times CO_2$), that "constraint" instead implies a large aerosol forcing.

In summary, global warming acceleration is a result of high climate sensitivity (proven by paleoclimate data) and large (negative) aerosol forcing (implied by high climate sensitivity and supported by the IMO "experiment"). Observed doubling of Earth's energy imbalance and the rising anomaly of absorbed solar radiation assure that an accelerated global warming rate will continue for at least a decade. Thus, the 2°C global warming limit will also be breached, unless purposeful actions are taken to reduce our present extraordinary planetary energy imbalance. In other words, if we wish young people to inherit a planet comparable to the one that has existed for the past 10,000 years, it will be necessary to reduce the enormous geoengineering of the planet that our human-made emissions have engendered.

2. CLIMATE POLICY

Climate change has become a great threat because of climate's delayed response to a forcing such as a human-made change of the atmosphere. Delayed response means that by the time human-made climate change is obvious and effects are widely understood to be detrimental, there is much more climate change "in the pipeline" that will be difficult to avoid. This delayed response makes climate change an intergenerational issue.

Climate change is a difficult problem for another reason: the principal source of greenhouse gases (GHGs) is fossil fuels, which are extremely beneficial to humanity. Fossil fuels have raised living standards almost worldwide and they still provide almost 80 percent of the world's energy. Fossil fuels are readily available, so the world will not give up their benefits without equal or better alternatives.

These characteristics make the climate problem difficult to solve. The policy actions must penetrate to the deep roots of fundamental matters, but the United Nations has not even attempted to address the basic problems, as we will discuss. Thus, the world has already entered a period of consequences, and, because of climate's delayed response, we are near a point of no return, a point at which extreme consequences spiral out of humanity's control. There remains but a narrow window of time to define and take actions to avoid that result.

We begin this policy discussion with a subsection in which the first author describes a few personal experiences that help clarify the basic policy requirements. Next, again using personal examples, we try to explain the reluctance of the scientific community to reveal the stark reality of the climate situation to the public. With that background, we discuss the three actions that are required to successfully address climate change and achieve a bright future for today's young people and their children. Then we discuss why we believe that a happy ending is still possible and how young people should be invigorated, not depressed, by the current situation. Finally, we respond briefly to commentaries on our *Pipeline* paper.

2.1 A Personal Education in Policy

In 2000, after 25 years of research in climate science, I was concerned that all IPCC scenarios led to dramatic, undesirable, changes of the planet to which civilization was adapted. Thus, with help of several colleagues, I suggested an "alternative scenario,"[26] a slow phasedown of CO_2 emissions in the first half of the 21st century that we argued was possible with increased emphasis on energy efficiency and development of clean energies. We included a focus on pollution that affects human-health (black soot, ozone, and methane, which affects low level

ozone). Our rationale was that this would unite the interests of developed and developing countries. We had no experience in policy, but Gerry Lenfest responded to our plea and provided funding that allowed us to hold large 5-day workshops at the East-West Center in Hawaii, in 2002 and 2005, in which we included climate, energy, health and policy scientists from China, India, the United States, and Europe.[27] It was a beginning.

Expanded opportunities arose after I gave a talk[28] criticizing the Bush Administration's energy policy shortly before the 2004 Presidential election and an updated version[29] of the talk at the 2005 American Geophysical Union meeting. Calls from the White House to NASA requesting that I be silenced, as documented by Mark Bowen in a book[30] and on his website, resulted in unconstitutional restrictions on my ability to speak to the media. Hullabaloo that followed led to opportunities for extensive policy-relevant interactions with politicians, utility CEOs and their staffs, oil and coal executives, and environmentalists in at least a dozen countries.[31] A few highlights help expose major policy failures that continue today.

Carbon fee. It was clear (from graphs of emissions) that the wishful-thinking policy approach of the Kyoto Protocol, in which each nation is asked to please reduce emissions, is ineffectual. An invitation to give a talk on the Kyoto Protocol on July 4, 2008, at the United Nations University in Tokyo, coincident with a G8 meeting hosted by Japan, was a chance to deliver a letter to Prime Minister Fukuda of Japan.[32] I had concluded that the essential policy is what I first called "carbon tax and 100% dividend," a tax collected from fossil fuel companies at domestic mines or ports of entry, with the funds distributed to the public as a dividend (I changed the name to "fee and dividend" in 2009). We also noted the need for "an import duty on products produced in other countries that do not impose a comparable carbon tax," as an incentive designed to make the carbon fee near-global.

A near-global carbon tax or fee is the basic policy action needed to limit and then bring down human-made climate change. It's the *sine qua non*: a carbon fee is essential to address the "tragedy of the commons," the fact that waste products from fossil fuels can be dumped in the atmosphere freely. At present, without a near-global carbon fee, reduced emissions in some nations serve to reduce demand, make fossil fuels cheaper, so the fuels will be burned somewhere. Economists now widely agree on the need for carbon fee and dividend.[33] Its simplicity is essential, avoiding the loopholes in cap-and-trade schemes and offsets, which are all designed to allow payoffs to special interests.[31]

In retrospect, my letter probably focused too much on the need to phase out coal and leave unconventional fossil fuels in the ground. Climate got little attention at the G8. The rushed trip to Japan seemed to provide only an opportunity for pertinent sarcasm.[34]

Corollary to carbon fee. Discussions with CEOs and staffs of three utilities (Duke, PSE&G, and Florida Power and Light) in 2008 raised an issue. They did not dispute the merits of a rising carbon fee, but they still planned to use fossil fuels to provide baseload dispatchable power to complement intermittent renewable energy, especially in the Eastern United States, where hydropower is limited. If we want carbon-free electricity, they said, the government should support nuclear power the way it supports renewables via the subsidy of renewable portfolio standards. Without "clean energy portfolio standards" and government policies more supportive of nuclear power, utilities will continue to burn fossil fuels for many decades. Thus, the corollary to carbon fee & dividend, as I described in a letter to President-elect Obama[35] in late 2008, was the need for support of modern nuclear power.

East-West cooperation. The second major policy requirement, in addition to a carbon price, is the need for the West to cooperate with nations with emerging and developing economies. Fossil fuel additions to atmospheric CO_2 are long-lived, so global warming caused by human-made emissions is proportional to cumulative (historical) CO_2 emissions.[36,37] Developed

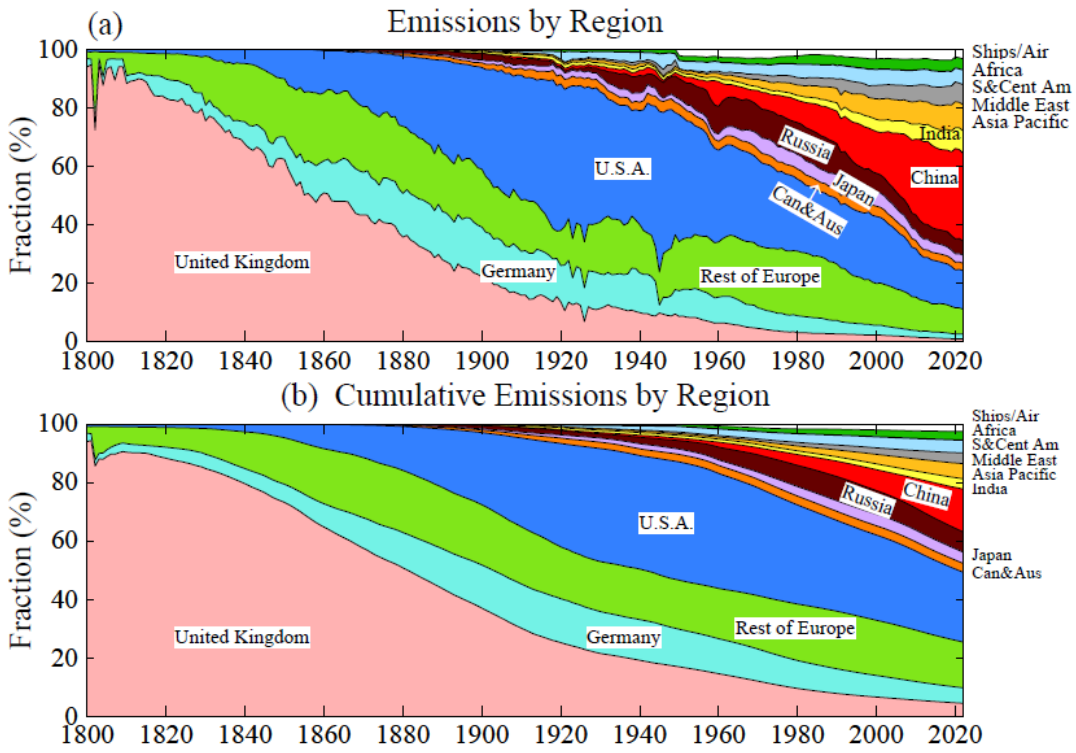

Fig. 9. Fossil fuel CO_2 emissions by nation or region as a fraction of global emissions. Data sources: Hefner *at al*.[38] and Energy Institute[39]

nations in the West, as of today, are responsible for more than half of cumulative emissions (Fig. 9b), but current emissions are more from China and other emerging and developing economies. (Fig. 9a). On a per capita basis, the responsibility of the West for climate change is still clearer (Fig. 10). Fossil fuels have been a boon, helping to raise living standards, but it is now clear that further CO_2 emissions must be limited to obtain a bright future for all humanity. Little is gained by arguing about responsibilities for emissions, but much can be gained for everyone by East-West cooperation to reduce future emissions.

Cooperation seemed possible a decade ago, when the Kissinger Institute on China and the United States invited me to a symposium on U.S.-China relations in Beijing – titled "New Type of Great Power Relationship" – focused on climate and public health. This was during the Obama administration and seemed promising. Tom Frieden,[40] Director of the Center for Disease Control, was the other invited scientist on the American side. The Chinese scientists were the thinktank of China's State Council. My presentation[41] was a summary of the climate threat and the opportunity for U.S.-China cooperation to address that threat.

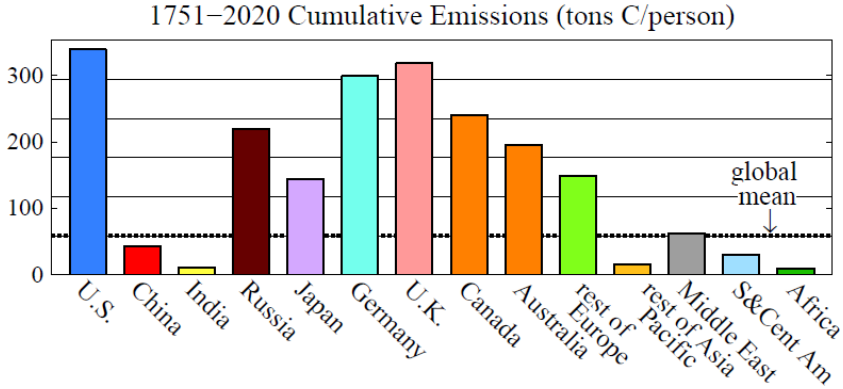

Fig. 30. Cumulative per capita national fossil fuel emissions.[42]

The clear need is to replace the world's huge fossil fuel energy system with clean energies, which likely would include a combination of "renewables" and nuclear power. Even if the renewables provide most of the energy, engineering and economic analyses indicate that global nuclear power probably needs to increase by a factor of 2-4 to provide baseload power to complement intermittent renewable energy, especially given growing demands of China, India and other emerging economies. The scale of China's energy needs makes it feasible to drive down the costs of renewables and nuclear power below the cost of fossil fuels.

The Chinese hosts gave us tours of large, new, facilities making solar panels and windmills, and Chinese mayors described plans to expand renewable energy use – yet their coal use was growing rapidly. When I asked about the absence of nuclear power from the agenda, the response was that the U.S. government seemed to have little interest in nuclear power. Thus, immediately following the Beijing symposium, I worked with American nuclear experts and Chinese colleagues to organize a workshop to define potential China-U.S. cooperation to advance nuclear power, intending it to be held at the East-West Center in Hawaii. When I struggled to find funding, Junji Cao offered to host the workshop in Hainan, China.

We published a workshop summary in *Science*.[43] We suggested that a large reduction of cost and construction time was possible via mass manufacturing, analogous to ship and aircraft construction, with product-type licensing that avoids long delay and cost associated with case-by-case approval. Collaboration on next-generation technologies requires government and industries to balance interests in cooperation and competition. However, each country has a major stake in the other's success in reducing its carbon emissions.

A memorable aspect of the Hainan workshop was attendance of Kejun Jiang and discussion with him. I had asked Junji Cao to invite Jiang, because of my impression that Jiang had the greatest expertise on China's energy and carbon emissions planning. Remarkably, Jiang made the trip from Beijing for our brief side-discussion in which I described the potential merits of fee-and-dividend for China and the U.S., as both countries have growing wealth disparities in their public and both need to reduce CO_2 emissions. Jiang agreed, saying "let's write a paper on it." That paper never happened. We first had long fights to publish the nuclear workshop paper (we learned that the liberal media bias against nuclear power extends to some scientific journals, as will be described in *Sophie's Planet*, which will eventually be published) and an equally difficult battle to publish and defend our *Ice Melt* paper. Then Donald Trump was elected President of the U.S., practically eliminating cooperation with China.

2.2 Scientific Reticence and Policy

Scientific reticence is discussed in section 7.2 of *Pipeline.*[1] Here I give more revealing detail on a specific case. In 2015 we submitted our *Ice Melt* paper[44] to *Atmospheric Chemistry and Physics* with the title *Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations implies that 2°C warming is highly dangerous.* The paper was extensively peer-reviewed. Three of four reviewers agreed that it should be published; the fourth reviewer, an IPCC lead author, seemed particularly incensed by the paper's title. The most offending phrase was "2°C warming is highly dangerous."

In discussion with the editor, it became clear that the crucial issue was interpretation of the word "dangerous." That word appears only once in the 1992 United Nations Framework Convention on Climate Change (UNFCCC),[45] as follows "…to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner." The

word “dangerous” is not further defined, and that is probably for good reason: the public understands what “dangerous” means. Thus, I wrote[46] to the editor:

“Let us give an analogy. Say there is a poorly lit street frequented by gangs, thugs and robbers, which police reports indicate has continually been the location of crimes, and newspapers have reported such. A person looking down this street late at night and seeing a number of loiterers, one seemingly with a blackjack in his hand, might well conclude that it would be dangerous to go down that street. What is shown in our paper is analogous. It [a planet 2°C warmer] would be dangerous in a sense that people would understand.”

Here is the kicker: the editor told me that if I included the above paragraph in my official letter of response (which would be published on the ACP website, as all correspondence is to be published in their open review process), they would not accept our paper for publication. Today, I am still bothered by the censorship of that paragraph. What was the editorial board thinking? Did they realize that they may be wrong and did not want to be exposed? In any case, I was exhausted and had to accept their constraints or not publish the paper. We had worked on *Ice Melt* for several years, taking pains to minimize unphysical ocean mixing that reduced the sensitivity of most GCMs to growing freshwater injection from ice melt and from an amplifying hydrologic cycle. We were confident in our conclusion that continued high GHG climate forcing would cause shutdown of the AMOC (Atlantic Meridional Overturning Circulation) and its Southern Hemisphere cousin (SMOC) this century, possibly by midcentury, and then sea level rise of several meters on a time scale of 50-150 years. These conclusions were based not only on our GCM modeling, but also on paleoclimate evidence, especially from the Eemian period, and on ongoing observations.

The result was we had to change the title from “…is highly dangerous,” not to my proposed compromise (“…is dangerous,”) but rather to “…could be dangerous,” a nothing-burger – we could have concluded that without writing a scientific paper. To top it off, the IPCC/GCM community was ready with a publication intended to kill our paper. The 15 authors, from leading GCM groups, used 21 climate projections from eight “…state-of-the-science, IPCC class…” GCMs to conclude that the “…likelihood of an AMOC collapse remains very small (<1% probability) if global warming is below ~5K… ”.[47] They treated the ensemble of their model results as if it were the probability distribution for the real world! Their paper must have been the basis on which IPCC blackballed our paper.[1] We expect that IPCC, over the next couple of decades, will reach conclusions similar to ours. The problem is that, given a climate system with delayed response and amplifying feedbacks, it is possible to be too late.

2.3 Three Fundamental Policy Requirements

Section 7.5 of the Pipeline paper, “climate and energy policy,” discusses three main policy needs: (1) a rising price on GHG emissions, enforced by border duties on products from nations without a carbon fee; but that is not enough – long-term energy planning consistent with phaseout of fossil fuel emissions over the next few decades is needed, which in many nations, if not most, implies the need for rapid development of modern nuclear power, (2) real global cooperation, in particular between the United States and China, countries with the two largest economies and the greatest GHG emissions; the present politically-driven choice to define China as an enemy, rather than negotiate fair relationships, threatens the future of young people, (3) a multitude of actions are required within less than a decade to reduce and even reverse Earth’s energy imbalance for the sake of minimizing the enormous ongoing geoengineering of the planet; specifically, we will need to cool the planet to avoid consequences for young people that all people would find unconscionable.

For the sake of getting this done today, I am also writing these latter sections in first person, but my opinions and the technical information are influenced by my long-time colleagues, especially Pushker Kharecha, Makiko Sato, Daniel Galpern, and Eunbi Jeong.

2.4 Is there a solution with a happy ending?

None of the three fundamental policy actions are presently occurring. Nor are they even on the agenda of the COP (UN Conference of the Parties) meetings. Our ex-student and research scientist, Surabi Menon, now a staff member of ClimateWorks on leave of absence to work six months for COP28, tried to get me on the agenda there. Unsurprisingly, given the *Pipeline* message that I would have been carrying, she did not succeed in getting me on the agenda. That's one reason I decided not to attend COP28. I believe that it's more important to try to help young people understand what is driving climate change, what are the consequences, and what we can do to obtain the most beneficial outcome.

Why am I optimistic about the possibility of a happy ending to the climate crisis? Mainly because of all the bright young people who can understand what is needed and are willing to work to make it happen. More than 350 college student body presidents, from all 50 U.S. states, have come out in favor of following the science, specifically in support of carbon fee and dividend.[48] Even high school students[49] can understand the matter. Young people are not carrying all the baggage, the indoctrinations about what constitutes clean energy, that older people seem to be saddled with.[50] Young people can see and understand that the old geezers running the world are geoengineering the planet to destruction.[51]

Here we are out of time for discussion, but we note that we are planning a paper with some of these young people, and scientists such as Eric Rignot who have the best present estimates for how much time we have before it is too late to take actions to cool Earth. It may take at least several years for nature and science to help the powers that be (mostly the public) understand the need to cool the planet. Such actions only make sense if we are simultaneously doing everything possible to reduce atmospheric GHGs. These matters will be discussed in *Sophie's Planet*,[52] which should be finished in 2024.

2.5 Response to Scientific Commentary

It should be sufficient to respond to the main comments of Zeke Hausfather, Michael Mann, and Johan Rockstrom. They are all outstanding scientists and exceptional communicators.

Zeke Hausfather's comment relayed to me was that we are "out of the mainstream." That is a correct summary. We use well-founded paleoclimate data to infer that equilibrium climate sensitivity is much higher than IPCC's best estimate. Also, we use multiple lines of evidence to infer that the (negative) aerosol climate forcing is larger than IPCC estimates. High climate sensitivity and declining aerosol forcing are the reason for the shocking increase of Earth's energy imbalance and, thus, the acceleration of global warming that is now underway.

Johan Rockstrom, in contrasting his view of the situation and mine, notes that global fossil fuel emissions declined 7% in the first covid year and suggests that a similar reduction every year would largely deal with the climate problem. I don't disagree with that, but no energy expert I have met believes that such a rapid reduction is plausible, and the West has no right to demand that nations working to raise their living standards reduce their emissions 7% per year. Also, I note that our data show only a 5% drop of emissions in the covid year, not 7%.

Michael Mann says that he doesn't see any acceleration of global warming. Some people would say that the acceleration is already apparent, but the level to which global temperature rises by next May and then falls in the next La Nina, will firmly settle that matter.

Mike also says that he doesn't see an increase in the rate of heat uptake by the ocean. Fig. 4 (by Li *et al*.) in our prior communication[21] shows that there is evidence of increased heat uptake even in the long-term *in situ* ocean data, which have large error bars because of the difficulty in obtaining adequate coverage of the global ocean with consistent instrument calibrations. However, our analysis refers to the changes underway in the 21st century, when we have much more precise data on Earth's energy imbalance from the combination of *in situ* Argo ocean data and satellite CERES data (Fig. 7 above). The increase of absorption of solar radiation by Earth and the increase of Earth's energy imbalance are much larger than the measurement uncertainty. The measurements need to be continued![53]

Mike also says that our paper is "wrong" because nations and industries and businesses are promising to go to zero emissions or net zero emissions in the future (sometimes in the far future, when the promiser will be dead or at least out of office). Leaving aside whether the promisers can all be trusted to deliver and whether their concept of "net zero" is really zero (very big assumptions!), the present global warming and planetary energy imbalance assure that we will hit 2°C global warming. Present knowledge of the consequences of ZEC (Zero Emissions Commitment, the change in global mean temperature expected to occur following cessation of net CO_2 emissions), MacDougall *et al*.,[54] indicates an approximate stabilization of global temperature from the time at which ZEC is achieved. As for the realism of the assumptions of near-term achievement of ZEC, one would be wise to read the opinions of Dyke, Watson and Knorr,[55] who have had the real-world experiences needed to grasp the nature of the present situation.

2.6 Appeal for financial support

In 2023, we (CSAS, Climate Science, Awareness and Solutions) made good progress thanks to an especially generous contribution from our long-term supporter Jeremy Grantham and a new supporter (Eric Lemelson). I hope that we did not overlook other supporters from the past few years in the acknowledgements of our *Pipeline* paper: [CSAS is a 501(C3) non-profit supported 100% by public donations. Principal supporters in the past few years have been the Grantham Foundation, Frank Batten, Eric Lemelson, James and Krisann Miller, Carl Page, Peter Joseph, Ian Cumming, Gary and Claire Russell, Donald and Jeanne Keith Ferris, Aleksandar Totic, Chris Arndt, Jeffrey Miller, Morris Bradley and about 150 contributors to annual appeals.] The extra support in 2023 allowed us to hire two talented young people, Isabelle Sangha and Joe Kelly, whose help was essential in completing the *Pipeline* paper.

In 2024, we have a special, one-time, need because Makiko Sato will be retiring at the end of the year and we need to continue her remarkable work in obtaining, updating, and helping us understand the huge number of data sets that are needed to analyze climate change. We need temporal overlap of a new person with Makiko, preferably for at least six months.

Contributions are equally useful to CSAS at Columbia University or CSAS.inc, both of which are 501(C3) non-profits. CSAS at Columbia supports those people with Columbia University appointments while CSAS.inc supports all other costs without overhead. Instructions for donations are at:
CSAS-CU: https://csas.earth.columbia.edu/giving
Inc donations: https://www.climatescienceawarenesssolutions.org/donate

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[1] Hansen J, Sato M, Simons L *et al*. Global warming in the pipeline. *Oxford Open Clim Chan* 2023;3(1):kgad008, doi.org/10.1093/oxfclm/kgad008

[2] CFC use was curtailed after it was realized that disassociation of CFC molecules in the stratosphere led to destruction of the ozone layer, which protects life on Earth from harmful ultraviolet sunlight. If CFCs had not been curtailed, today's climate would now be so warm as to constitute a different planet

[3] The noise is due mainly to fluctuations in the annual growth of atmospheric CO_2. Fossil fuel emissions of CO_2 change only slowly, a few percent per year, but growth of CO_2 in the air is erratic. Averaged over several years the growth of CO_2 in the air averages only about 55% of the fossil fuel emissions, because CO_2 "sinks" – the ocean, soil and biosphere – take up a large portion of the CO_2 emissions. These sinks fluctuate from year-to-year mainly because of climate variability, e.g., droughts can turn a CO_2 sink into a temporary source.
[4] Hansen J, Sato M. Greenhouse gas growth rates. *Proc Natl Acad Sci 2004;***101**:16109-14
[5] IPCC. *Climate Change 2021: The Physical Science Basis [Masson-Delmotte V, Zhai P, Pirani A et al. (eds)]*. Cambridge and New York: Cambridge University Press, 2021
[6] A small part of this 4.1 W/m^2 is "slow feedback," i.e., it is engendered by climate change. The convention is to use the precisely observed GHG amounts in calculating climate change. Separate studies including the carbon and nitrogen cycles are needed to estimate the portions of CO_2, CH_4, and N_2O change from feedbacks. Most of the observed increases are traced to human-made sources.
[7] Creutzig F, Erb KH, Haberl H *et al*. Considering sustainability thresholds for BECCS in IPCC and biodiversity assessments. *GCB Bioenergy* 2021;**13**:510-5
[8] Hansen J, Rossow W, Fung I. *Long-term monitoring of global climate forcings and feedbacks*. Washington: NASA Conference Publication 3234, 1993
[9] In a National Science Foundation project (CLIMAP) culminating in about 1980, it was estimated that the LGM was 3.5°C colder than the Holocene. That result depended on LGM sea surface temperatures (SSTs) inferred from the geographical distribution of microscopic biological species recorded in ocean sediment cores, based on the assumption that these species migrated to stay within temperature zones where they exist today. But what if species partly adapt on millennial time scales to change of temperature? In such case, CLIMAP underestimated LGM cooling. Recent LGM studies (Tierney JE, Zhu J *et al. Nature* 2020;**584**:569-73; Osman MB, Tierney JE *et al. Nature* 2021;**599**:239-44) exclude the biological species data, instead relying on chemical tracers and using a GCM to get a realistic global pattern of temperature change, thus finding global cooling of 7°C at the LGM maximum. An independent analysis (Seltzer AM, Ng J *et al. Nature* 2021;**593**:228-32) of temperature-dependent noble gas abundances in groundwater deposited during the LGM finds cooling of 6°C on land areas 45S to 35N, which is consistent with the global full-LGM cooling found by Tierney *et al*., as shown in *Pipeline*.
[10] Sustainable Development Solutions Network (SDSN). Nov 3, 2023. *An Intimate Conversation with Leading Climate Scientists to Discuss New Research on Global Warming* [Webinar]. YouTube: https://www.youtube.com/watch?v=NXDWpBlPCY8
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[12] Jiang X, Su H, Jiang JH, *et al.* Muted extratropical low cloud seasonal cycle is closely linked to underestimated climate sensitivity in models. *Nat Comm 2023;***14(1)**:5586, doi:10.1038/s41467-023-41360-0.
[13] References for the International Maritime Organization documents are in our *Pipeline* paper (ref. 1 above)
[14] Ship changes likely phased in the year leading up to January 2015 and January 2020.
[15] Jin Q, Grandey BS, Rothenberg D *et al.* Impacts on cloud radiative effects induced by coexisting aerosols converted from international shipping and maritime DMS emissions. *Atmos Chem Phys* 2018;**18**:16793-16808
[16] Loeb NG, Johnson GC, Thorsen, TJ *et al.* Satellite and ocean data reveal marked increase in Earth's heating rate. *Geophys Res Lett* 2021;**48**:e2021GL09304
[17] The average solar energy incident on Earth is about 340 W/m^2.
[18] Lenssen NJL, Schmidt GA, Hansen JE *et al.* Improvements in the GISTEMP uncertainty model, *J Geophys Res Atmos* 2019;**124(12)**:6307-26
[19] Hansen J, Ruedy R, Sato M *et al.* Global surface temperature change. *Rev Geophys* 2010;**48**:RG4004
[20] As an alternative derivation, let's first assume that the aerosol forcing (added in two steps, 2015 and 2020) is 1 W/m^2. That forcing would produce 0.3-0.4°C global warming by now (Fig. 3). With El Nino raising global temperature 0.1-0.2°C above the trend line and aerosol forcing adding 0.3-0.4°C to global warming, we would project peak 12-month-mean warming 0.4-0.6°C above the trend line in May 2024, thus including the possibility of warming slightly above the 1.6-1.7°C range estimated in *Pipeline* (pink region, Fig. 4).
[21] Hansen J, Kharecha P, Loeb N, Sato M, Simons L, Tselioudis G, von Schuckmann K, How we know that global warming is accelerating and that the goal of the Paris Agreement is dead, 10 November 2023
[22]That dynamical process is normal during an El Nino, but the weekly forecasts of the NOAA model have persistently failed to simulate this amplifying feedback during the current El Nino, instead suggesting that the El Nino already peaked. The average of other dynamical models seems to be more realistic, yielding a peak Nino3.4 of ~2.0, which would make this El Nino comparable in strength to the 2015-16 El Nino. Weekly updates of forecasts and observed data are available at: https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/enso_evolution-status-fcsts-web.pdf
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[32] Hansen, J. Dear Prime Minister Fukuda: A letter to leader of Japan before the G8 meeting, 3 July 2008
[33] Economists' statement on carbon dividends (28 November 2022, date last accessed)
[34] The letter to Fukuda ended: Finally, Prime Minister Fukuda, I would like to thank you for helping make clear to the other leaders of the eight nations the great urgency of the actions needed to address climate change. Might I make one suggestion for an approach you could use in drawing their attention? If the leaders find that the concept of phasing out all emissions from coal, and taking measures to ensure that unconventional fossil fuels are left in the ground or used only with zero-carbon emissions, is too inconvenient, then, in that case, they could instead spend a small amount of time composing a letter to be left for future generations. This letter should explain that the leaders realized their failure to take these actions would cause our descendants to inherit a planet with a warming ocean, disintegrating ice sheets, rising sea level, increasing climate extremes, and vanishing species, but it would have been too much trouble to make changes to our energy systems and to oppose the business interests who insisted on burning every last bit of fossil fuels. By composing this letter, the leaders will at least achieve an accurate view of their place in history.
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[51] Operaatio Arktis
[52] Hansen J. *Sophie's Planet*, draft.
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