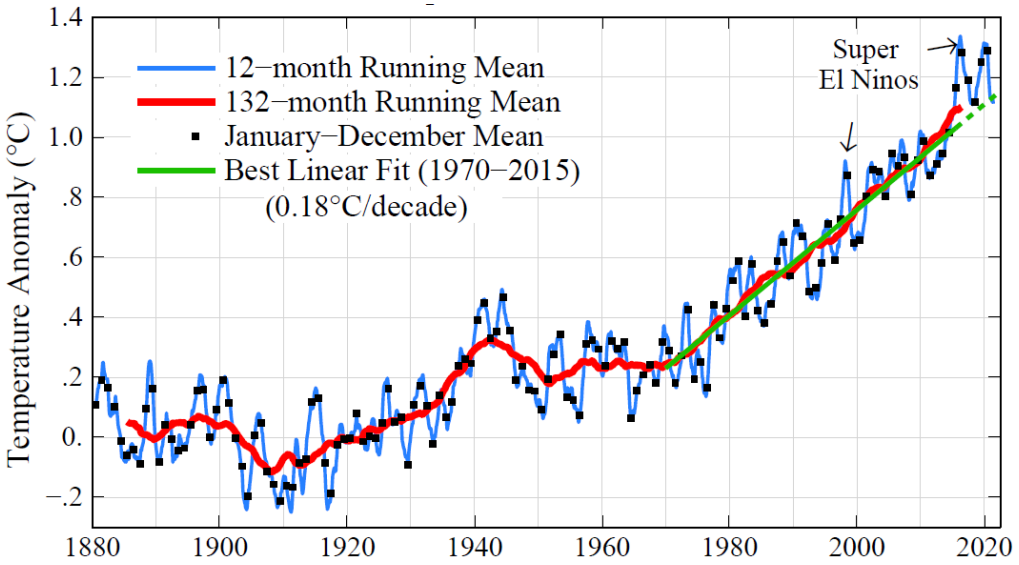

Fig. 1. Global surface temperature relative to 1880-1920 average.

November Temperature Update and the Big Climate Short

23 December 2021

James Hansen, Makiko Sato and Pushker Kharecha

Understanding of short-term climate variability helps to illuminate long-term climate trends and reveals that the 1.5°C global warming ceiling will be breached this decade. This use of the word "short" is unrelated to the Big Climate Short that is being foisted on young people by political leaders with the assistance of climate modelers.

November global temperature was +1.19°C relative to 1880-1920, the 4th warmest November in the Goddard Institute for Space Studies analysis for the 1880-2021 period of near-global data. Annual 2021 global temperature should be the sixth warmest year in the record, barely edging out 2018. The seven warmest years in the record all occurred in the past seven years.

The 2021 annual mean global temperature will fall almost smack on the 1970-2015 trend line. So, can we continue to say that we are in a period of accelerated global warming? Yes, for sure, based on knowledge of factors that cause most of the short-term global temperature variability. Long-term change becomes more apparent, when we account for short-term variability.

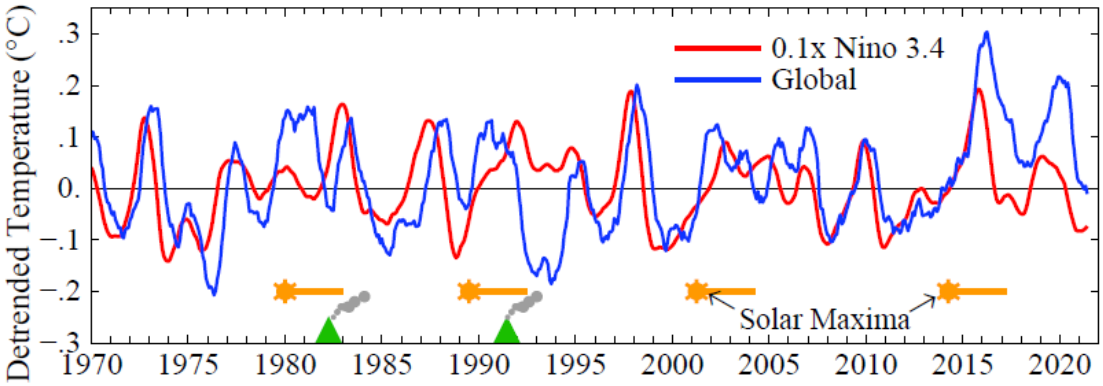

Fig. 2. 12-month running-means of global and Nino3.4 temperature anomalies relative to 1970-2015 trend lines. Green triangles = large volcanoes. Gold bars = 3 years following solar maxima.

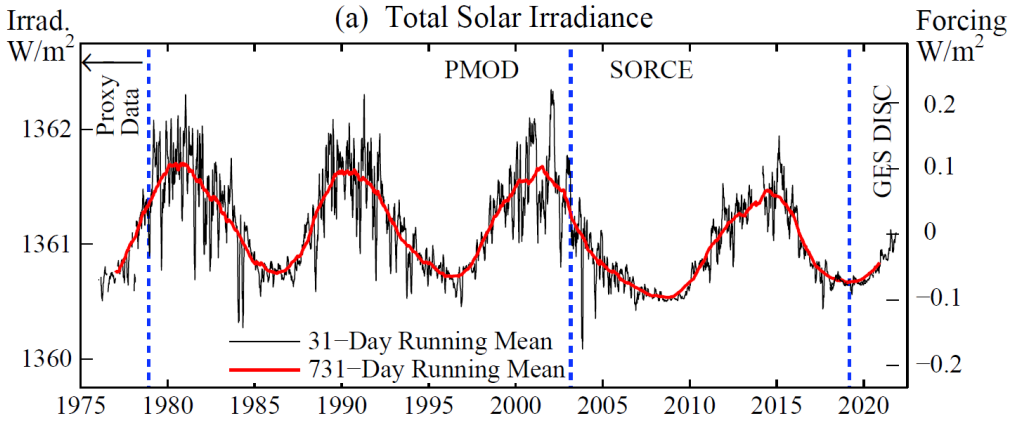

Fig. 3. Total solar irradiance variations (left scale) and associated climate forcing (right). For an explanation of data sources in the four indicated periods, see Greg Kopp's webpage.

El Nino/La Nina oscillations in the tropical Pacific are the principal cause of short-term global temperature variations. Global temperature anomalies relative to the 1970-2015 trend line are compared in Fig. 2 with anomalies in the standard Nino3.4 region off the South American coast. The correlation is 61%. Global temperature lags the Nino3.4 anomaly by 5 months.

The correlation of global and Nino temperatures is reduced by external climate forcings. Stratospheric aerosols from large volcanic eruptions and solar irradiance variations are climate forcings that contribute to global temperature change. The greatest aerosol injection of the past 100 years, by the Mt. Pinatubo eruption in 1991, caused a notable cooling in the following two years. (Fig. 11 of reference 1 shows the impact of Mt. Pinatubo on Earth's energy balance.[1] The smaller 1982 El Chichon eruption had little noticeable effect, as it coincided with an El Nino.)

Solar irradiance variations have a detectable effect on global temperature. The amplitude of the ~11 year solar cycle is about 0.1% (Fig. 3). Solar heating of Earth[2] is about 240 W/m^2, so the 0.1% variation is a forcing of about 0.24 W/m^2. Equilibrium climate sensitivity is about 3°C for a doubled CO_2 forcing of 4 W/m^2, or about 0.75°C per W/m^2. The ~11-year periodicity of the solar forcing allows the global surface temperature to reach almost half of the equilibrium fast-feedback response – see response function[3] on p.13 of reference 3 – so the full amplitude of global temperature response to the solar cycle is about 0.1°C. Ocean thermal inertia causes the maximum warming effect of solar variability to occur in the three years beginning at solar maximum, as shown by gold bars in Fig. 2.

Taking account of these sources of short-term global temperature variability, and recognizing that the growth rate of greenhouse gas (GHG) climate forcing has been relatively steady for the past several decades, it's clear that the 7-year period 2015-2021 is anomalously warm (Fig. 2). As discussed in our July temperature update,[4] the excessive warming can be traced to a reduction of human-made aerosols; thus, the warming is the first payment in our Faustian aerosol bargain.[5]

Leon Simons, as noted in the July update, pointed out the coincidence of the excess warming with implementation of strict sulfur emission limits on ships in the North Pacific and North Atlantic regions. Aerosol reduction causes reduced cloud cover and thus increased absorption of solar radiation. Satellite measurement[6] of reduced reflectance of sunlight in these regions supports this interpretation for the cause of accelerated warming.

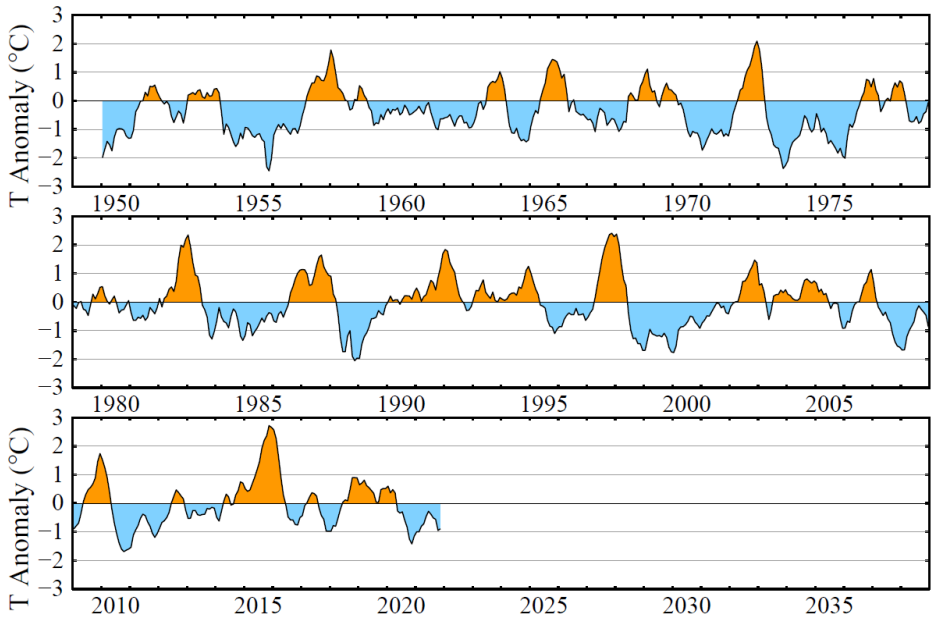

Fig. 4. Temperature anomaly since 1950 in Nino3.4 region relative to 1991-2020 mean. Data through November 2021. Data source: NOAA Climate Prediction Center El Ninos (part of the orange area) are defined by the NOAA Climate Prediction Center as the periods when this temperature anomaly exceeds +0.5°C for three consecutive months.

The 12-month running-mean temperature will rise with the Nino cycle in the next six months, and warming will be accelerated by Earth's largest energy imbalance in the past half century.[7,8,6] Increased solar irradiance will add about 0.1°C to global temperature by the second half of the 2020s. Thus, the 1.5°C ceiling will be breached with even a moderate El Nino in the later 2020s, which will almost surely occur (Fig. 4).

The *Big Climate Short* will dwarf Wall Street's 2007-2008 *Big Short*.[9] Perpetrators of the Big Climate Short stretch well beyond the usual suspects – people in search of power and money – and include many who will profess innocence or falsely claim hero status. Such protestations of innocence or ignorance will ring hollow to young people as the consequences of global climate change grow and the story of how it came about is illuminated.

In *A Realistic Path to a Bright Future*,[10] one of us (JH) described UK Prime Minister Boris Johnson's claim that COP26 salvaged the chance to keep global warming below 1.5°C as "pure, unadulterated bulls**t. There is now no chance whatever of keeping global warming below 1.5°C." Johnson also said: "while there is still so much that needs to be done to save our planet, we'll look back at COP26 as the moment humanity finally got real about climate change."[11]

Really? Where did he get that idea? Perhaps from COP26 President Alok Sharma, who, after the summit, said[12] "We can say with credibility that we have kept 1.5 degrees within reach, but its pulse is weak." Where did Sharma derive his claim of credibility? From climate models? Who was informing Sharma? It's possible to get almost any answer from models by inserting appropriate greenhouse gas scenarios, but models have a problem called GIGO: garbage in, garbage out. Climate models are essential and valuable for understanding climate change, but they form only one of the three legs of the tripod that climate knowledge stands firmly upon. The other two are Earth's paleoclimate history, which climate models must be consistent with, and ongoing observations of climate forcing factors and climate system response.

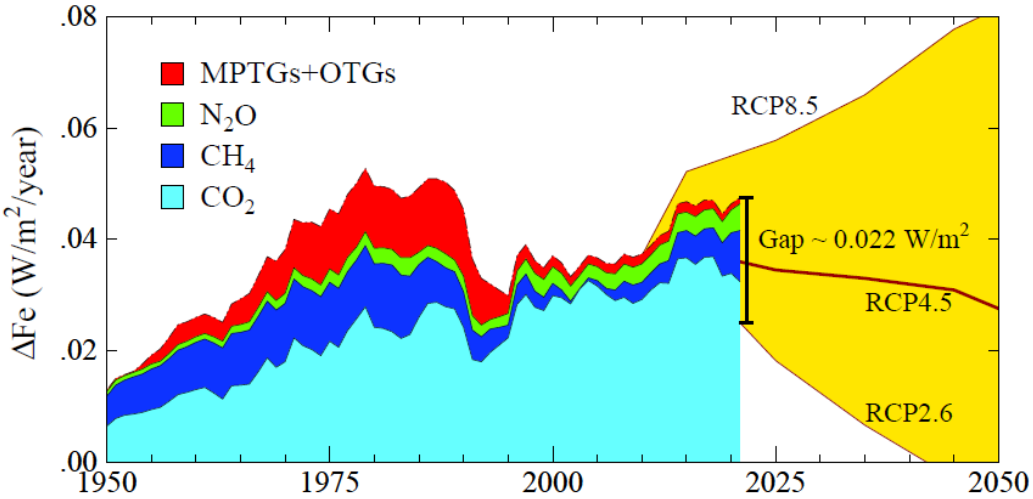

Fig. 5. Annual growth of greenhouse gas (GHG) climate forcing (red is trace gases, mainly CFCs). RCP2.6 is a greenhouse gas scenario designed to keep global warming below 2°C.

All climate scenarios in early IPCC reports yielded global warming of well over 2C, which led us to define an alternative scenario[13] in 2000 with equal emphasis on air pollution and CO_2. We thought it would probably take more than half a century to phase off fossil fuel CO_2 emissions. By focusing on air pollutants methane, black carbon, and tropospheric ozone, as well as CO_2, we concluded that it was still possible to keep global warming from exceeding 2°C. The alternative scenario had constant fossil fuel emissions in the first half of this century – which required an increase of carbon-free energies such as renewables and nuclear power – and declining fossil fuel emissions in the second half of the century. As described on page 13 of *Bright Future*,[10] this paper irritated the scientific community. A decade and a half later, the fifth IPCC Assessment Report (AR5) defined four scenarios: RCP (Representative Concentration Pathways) 2.6, 4.5, 6 and 8.5, where the number is the greenhouse gas forcing in 2100. RCP2.6 was defined so as to keep global warming below 2°C; however, emissions growth after 2000 meant that the 2°C limit could be met only by inserting a large dose of negative emissions.[14]

Now let's compare the real world with RCP2.6. Actual annual growth of the climate forcing – the upper edge of the red area in Fig. 5 – has increased in the past decade. Negative emissions required in 2021 to match the RCP2.6 scenario must reduce the annual growth of greenhouse gas climate forcing by 0.022 W/m^2. This gap between reality and the 2°C scenario can readily be converted – using accurate formulae in Table 1 of the alternative scenario paper[13] – to the atmospheric CO_2 reduction required to close the gap in added climate forcing during the single year 2021. However, as is well known, the required negative emissions (CO_2 extracted from the air and placed in permanent storage (which alternatively could have been reduced emissions) must be larger than the desired atmospheric CO_2 reduction by a factor of about 1.7 (see Fig. 10 of *Young People's Burden*[15]). Using the factor 1.7, the required CO_2 extraction (negative emissions) is 1.55 ppm atmospheric CO_2, which is 5.58 GtC.

What is the annual cost of this CO_2 extraction? In *Young People's Burden* – co-authors include carbon cycle experts Pete Smith and David Beerling – the unit cost is estimated as low as $150-350 per tC. The cost of extraction in that case is $0.84-1.95 trillion in 2021. The annual cost increases rapidly to stay on the RCP2.6 scenario. Moreover, the cost estimate of $150-350 per tC (which is $41-95 per t$CO_2$) is optimistic. Based on a pilot carbon capture plant built in Canada, David Keith[16] estimates an extraction cost of $450-920 per tC, as clarified elsewhere.[17] Keith's cost range yields an extraction cost of $2.5-5.1 trillion for the single year 2021.

The United Nations struggles to come up with a $100 billion climate fund for innocent nations suffering climate change. It's inconceivable that trillions of dollars per year will be found for CO_2 extraction. We conclude that the 1.5°C target certainly will be exceeded, and the world will almost certainly blow through the 2°C ceiling. Of course, one can devise a scenario that stays under 2°C via a miraculous transition to zero emissions within a few decades, but the real world pays no attention to imaginary scenarios. Instead, the real world responds to the actual growth of greenhouse gas climate forcings, shown by the top edge of the red area in Fig. 5.

What causes the yawning, growing gap between reality and the 2°C scenario? Fig. 5 reveals that the gap grew even during the economic slowdown caused by the covid pandemic.

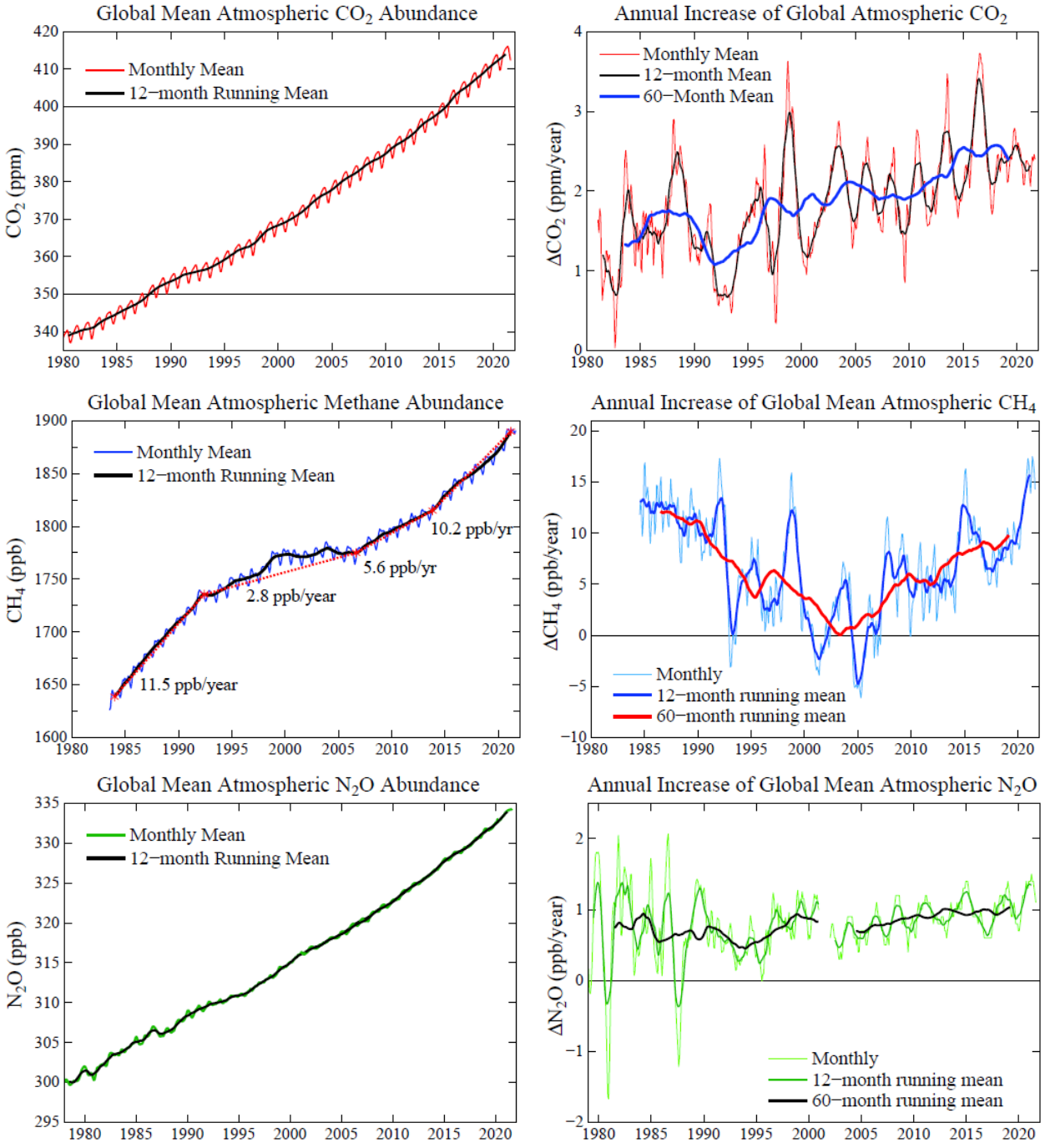

Fig. 6. CO_2, CH_4 and N_2O atmospheric abundances (left) and annual increases (right).

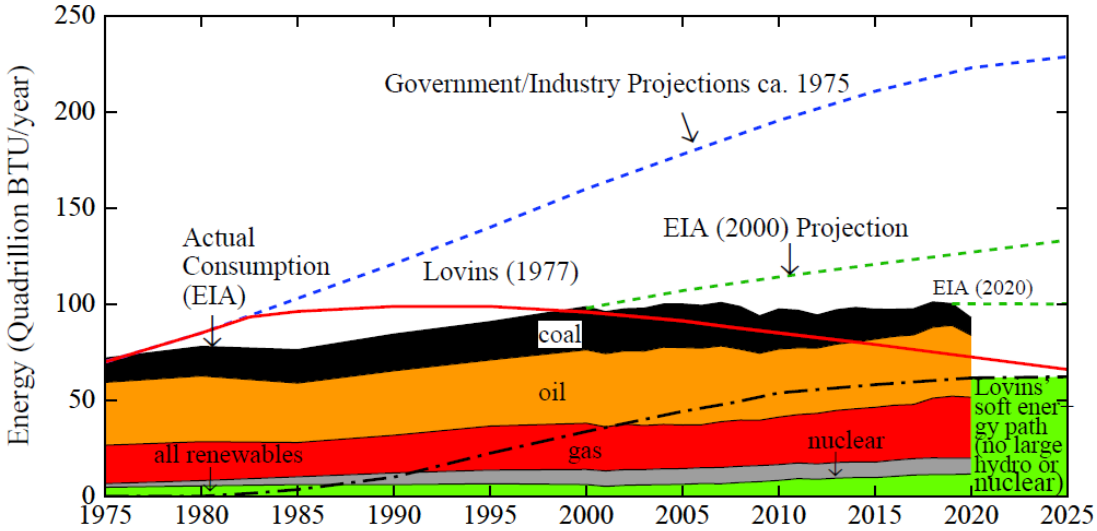

Fig. 7. United States energy consumption. Lovins projection for soft renewable energies (excludes large hydro), shown by the dash-dot line, was to provide all projected energy use (red line) by 2025. [Update of Fig. 2 in *Storms of My Grandchildren*.[5]]

The proximate reason that the GHG climate forcing growth rate did not decline is the increased growth of non-CO_2 gases – mainly methane (CH_4) – that compensated for a small decline in the annual growth of CO_2 during the past few years. [The small decline of CO_2 growth (Fig. 6, top row) is mainly a result of interannual climate variability rather than the fossil fuel source.] RCP2.6 requires a steep decline in methane emissions and methane atmospheric amount, but instead methane growth accelerated (Fig. 6, middle row). Growth of atmospheric nitrous oxide (N_2O) also continues, with the annual increment even growing (Fig. 6, lower row).

Growth of all of these gases is enhanced by amplifying feedbacks driven by global warming. Paleoclimate data reveal that the equilibrium atmospheric amounts of these gases increase with global temperature. "Natural" GHG sources such as wetlands and melted tundra increase with rising temperature. However, continued high humanmade emissions are the main reason that the GHG growth rates are not declining as required to stay within the 2°C scenario.

The underlying reason for the great overshoot of the 2°C scenario is failure of the world to develop a clean energy system for electricity. Instead, the West – or at least the liberal West – has adopted the fantasy of 100% renewable energy within decades, in which both nuclear power and fossil fuels are eliminated. Further, the West has instructed the developing world that it, too, must follow this fantasy. Consequently, President Clinton terminated research and development on nuclear power in the United States after his election in 1992. Germany, as the host nation for COP6 in Bonn in 2001, excluded nuclear power as a clean development mechanism under the Kyoto Protocol. Now, financing for fossil fuel or nuclear power plants is being denied to developing countries, even though the West used those energies to raise its own standards of living and continues to use those energies as needed to maintain living standards.

The 100% renewables vision was spurred mainly by Amory Lovins, who correctly projected in the 1970s that energy efficiency would allow less energy use than predicted by the Energy Information Agency.[18] However, his expectation that all fossil fuels, nuclear power and large hydro could be replaced by soft renewables is debunked by real world data (Fig. 7). Real world utility experts conclude that renewable energies must be complemented by reliable baseload electricity generation available 24/7 – either fossil fuels or nuclear.[10] For the sake of climate, the partner of renewables had better by nuclear power, not fossil fuels.

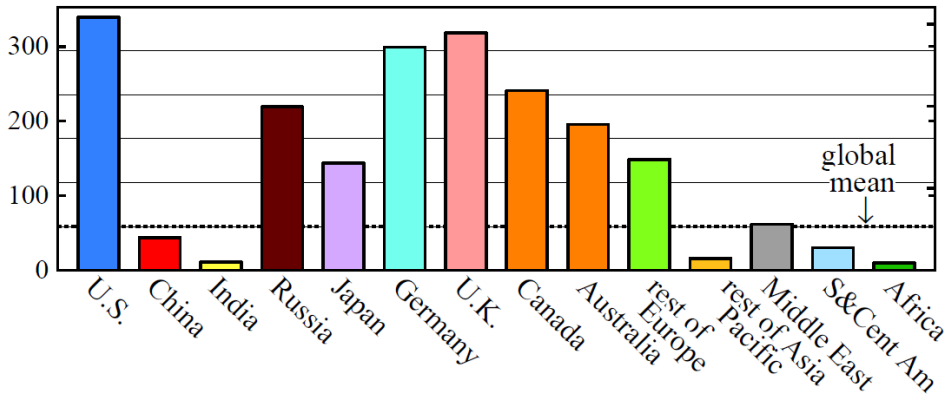

Fig. 8. Cumulative 1751-2020 fossil fuel carbon emissions (tons C/person; 2020 populations). Horizontal lines are multiples of the global mean.

The Big Climate Short has been handed to young people. They are inheriting an energy and climate system in which large climate change is now unavoidable. The United Nations and government leaders pretend that global warming, now at 1.2°C, can be curtailed with little additional warming. Capable scientists with an understanding of climate and energy know that this is pure, unadulterated bulls**t. Politicians who claim paltry successes while ignoring the elephants in the room[10] must be called out. We have sold our young people short.

It is possible to save a bright future for young people and the remarkable life that we share space with on our planet, but only with extraordinary efforts in both the political and scientific spheres. These will not happen without the active involvement of young people, supported by older people. It is not enough to stamp your feet and demand that governments do better. They won't, not on their own. It's necessary to know what is needed and work for it. More on that below.

Realpolitik and real politics prevent the sudden downturn of emissions that would be needed to avoid 2°C global warming.[10] Realpolitik includes practical constraints; all governments must keep the lights on, provide adequate energy at a reasonable price for the public and for industry; governments give priority to current needs over the climate of future generations. Realpolitik also includes the need to raise living standards. China and India have done little to cause global warming, which is proportional to cumulative emissions (Fig. 8), yet their future emissions may be the main drive for climate change. If the West is sensible, it will cooperate with China and India to help them obtain their energy needs with minimum emissions.[19]

That's where real politics comes in. Neither political party in the U.S. has a strategy that will result in rapid phaseout of U.S. emissions, let alone a global strategy.[20] The conservative party is openly in bed with the fossil fuel industry. There are lots of jobs in the fossil fuel industry – therefore lots of votes – and lots of "campaign" donations. The liberal party is little better. They early realized the votes in the anti-nuclear position and steadfastly blocked nuclear progress, e.g., with decades of subsidies in "renewable portfolio standards," which, for the sake of young people, should have been "clean energy portfolio standards."

Despite decades without support, modern reactors can be ready for commercial use within a decade or less, when they are most needed. Renewables can be added to an electric grid readily until they become a large fraction of total power and need support of reliable energy available 24/7. That complementary energy will be either nuclear or gas. If it's gas, that means fracking, that means pipelines, that means large climate change. The government could facilitate progress, but what is most needed is private investment. If modern nuclear power had a fraction of the investments being poured into renewables it would flourish. Members of the older generation with the wherewithal have an opportunity to be a savior of today's young people and nature.

The Big Climate Short will be exposed in the future, probably including a Hollywood film. It will be a strange movie, without heroes – although some may emerge from today's young people – but with bounteous villains. Analogy of the fossil fuel and tobacco industries is too simplistic. Unlike cigarettes, fossil fuels have been a boon to humanity, raising living standards. Of course, the industry improperly downplayed health and climate impacts, but people and nations wittingly tolerated fossil fuel pollution for the sake of cheap, abundant energy.

We scientists should first look in a mirror. Scientific caution has its merits, but with the delayed responses of the climate system and the longevity of CO_2 and other gases, have we been a tad slow with warnings? Do we rely too much on models that seem more lethargic than real world paleoclimate change and modern ongoing climate changes? How can we allow policymakers to believe that we may be rescued by scenarios with implausible greenhouse gas extraction?

Politicians, supposedly public servants, deserve special scrutiny. There is abundant evidence that our governments are heavily swayed by special financial interests. After almost a decade and a half of hearing politicians say "yes, a rising carbon fee and dividend would stimulate the economy and innovation without the need for a tax, but…" it's hard to believe that many of them are not cowardly or making money off the present situation, one way or another.

Mercenary "Big Green" organizations that accept money from the fossil fuel industry – as many of them do – and oppose nuclear power will earn contempt, as they continue to manufacture excuses for why they oppose the energy source with the smallest environmental footprint. They clap themselves on the back with each obstacle that they raise for the purpose of making construction of nuclear power slower and more expensive.

A highlight of the film will be a staged over-reaction to Fukushima by a Harry Reid acolyte as he goes bananas and tells Americans to evacuate Japan. Preceding that, Reid strong-arms George W. Bush to appoint the acolyte to the Nuclear Regulatory Commission and then strong-arms Barack Obama to elevate him to head the NRC.[21]

The media breathlessly report on the Fukushima emergency. Then they go on to a new story, failing to report that nobody died from the radiation release, but more than 1000 people died from the panicked evacuation that the media helped bring about. More generally, the media bear heavy responsibility for global nuclear fear that has practically locked in fossil fuels as the complement to renewable energies. They never report any good news about nuclear energy without "balancing" the story with scripted warnings, usually mouthed by an ex-NRC commissioner who was appointed to the NRC based on his anti-nuke credentials.

Another scene might have Big Green celebrating after the NRC issues a new stiffer requirement on radiation release – despite the sterling safety record of U.S. nuclear reactors, exceeding that of all other energy sources – demanding that all nuclear reactors design to a new ALARA (as low as reasonably achievable) standard. Cut to the nuclear engineer staring incredulously at the new order; he then throws up his hands yelling "no engineer can design to such a standard," decides to retire, and goes fishing with his grandchildren.

Hollywood may belong in the story as a branch of the media that has poorly informed the public, but Hollywood can justifiably claim that it was misled by scientists about the 100% renewable fantasy. Such disinformation is no wonder. Although most scientists recognize the need for reliable 24/7 nuclear power as a portion of a modern electric grid, there is a disincentive for pointing that out – a scientist questioning the 100% renewable religion may find himself labeled a "denier," making it difficult to find funding for climate research.

Global warming of at least 2°C is now baked into Earth's future. That level of warmth will occur by midcentury. Thus, it is now certain that Earth will soon be warmer than it was during the Eemian period. The Eemian, the prior interglacial period that lasted from about 130,000 to 115,000 years ago, was the most recent time that Earth was warmer than it has been during the present (Holocene) interglacial period.

What are the implications for policy? We have discussed political actions that need to occur – led by young people, but supported by all.[20] However, warming that reaches and exceeds the level of the Eemian also poses more demands on the science, which we have only hinted at.[10] Even the present global temperature is too high for keeping global shorelines close to their present locations. For that purpose, it will be necessary to return to global temperature no higher than the mid-20th century and probably a bit cooler. This will incidentally address most of the other problems for humanity that are caused by an overheated planet.

The one climate impact that almost everyone may agree is unacceptable is rapid sea level rise of several meters because it could mean loss of most coastal cities and is irreversible on any time scale that people care about. There is strong evidence that such an event occurred during the Eemian period. A brief time of rapid coral reef "backstepping" then – movement of reef-building toward the shoreline – indicates sea level rise of a few meters within several decades. Other geologic evidence is consistent with that rapid sea level rise.

The most likely source of that sea level rise was collapse of the West Antarctic ice sheet, which rests on bedrock well below sea level. Today it is again the most vulnerable ice sheet. West Antarctica per se contains enough ice for "only" about 4 meters of sea level rise, but its demise opens the door for additional mass loss from East Antarctica. The eventual sea level rise for global temperatures expected by the middle of this century is at least 10-15 meters.

A chief issue is the time scale required for such large sea level rise to occur. Estimates of the Intergovernmental Panel on Climate Change (IPCC) for likely sea level rise by 2100 have inched up over the course of the last few decades from a fraction of a meter to about 1 meter. The IPCC estimates are based largely on ice sheet models that are unable to reproduce rapid changes of sea level that occur repeatedly in the paleoclimate record.

The fact is that ice sheet disintegration is an exponential process with a characteristic time scale (doubling or e-folding time that characterizes exponential growth) of 10-20 years at maximum. That statement is proven by the fact that sea level rise of several meters per century has occurred many times in Earth's history. With a slower doubling time that sea level rise would be stretched over multiple centuries, in contradiction to the paleoclimate record. The picture that emerges is: when climate warming reaches a point that an ice sheet, or a portion of an ice sheet, is sufficiently out of equilibrium with its climate, ice sheet demise is a rapid exponential process.

Inchoate ice sheet models are not the only difficulty facing our desire to have an improved quantitative understanding of future sea level and its sensitivity to changing climate. There is also the fact that ocean models have difficulty producing a realistic response to increasing freshwater injection from melting ice sheets. Recently one of us (JH) wrote an article[22] that summarizes our 10-year research pathway that led us to conclude that most ocean models have excessive mixing of surface water into the deeper ocean, thus causing the models to be less sensitive than the real world to injection of freshwater into the upper ocean by melting ice.

At the invitation of the Editor-in-Chief of Oxford Open Climate Change, JH is now working on an article that discusses these modeling issues in the context of the crucial issue of future sea

level rise. It is our contention that IPCC has excessive reliance on models that still have fundamental shortcomings. We advocate a research approach that places comparable emphasis on (1) paleoclimate evidence for how the ocean, ice sheets and climate responded to climate forcings in Earth's history, (2) a range of global models that attempt to simulate paleoclimate and modern climate change, (3) modern observations of the climate processes that are most crucial in determining the ocean, ice sheet and surface climate response to the unprecedented forcing that humanity is imposing on the climate system.

We suspect that the overall climate research community has a view that is more in line with ours than with the heavy model emphasis of IPCC. This is not an esoteric or unimportant matter. Using our perspective with the limited available modeling capabilities, we[23] concluded that a continued business-as-usual growth of greenhouse gases likely will cause shutdown of the overturning North Atlantic and Southern Ocean overturning circulations (AMOC and SMOC, respectively) by the middle of this century.

AMOC shutdown would have substantial effect on climate and storminess in the North Atlantic and neighboring regions, but the more important effect may be reduction of heat transfer from the Southern Hemisphere to the Northern Hemisphere. Reduced heat export caused by AMOC shutdown adds to the warming of the Southern Ocean at depth. SMOC shutdown will close off the natural escape valve of deep Southern Ocean heat to the atmosphere and space. The resulting warming of the Southern Ocean is maximum at depths 1-2 km on the Antarctic coast, which is the depth of the ice shelves around Antarctica that buttress the land-based ice sheet.

The SMOC slowdown and eventual shutdown accelerate ice melt and sea level rise, thus helping account for evidence of rapid paleoclimate sea level rise. Continued growth of present Antarctic ice melt with the characteristic doubling time implied by paleoclimate data yields sea level rise of several meters near the end of the present century.

These processes and feedbacks urgently need to be understood better, because there is already evidence that AMOC and SMOC are slowing down and ice melt is accelerating. The slowdowns of AMOC and SMOC are not a smooth, linearly-increasing phenomenon. Long-term growing slowdown of SMOC and associated expansion of Southern Hemisphere sea-ice area, for example, was interrupted in 2015 by temporary increase of upwelling heat coincident with a super El Nino and with a temporary reduction of sea-ice cover. Subsequently, the slowdown of the overturning circulation seems to have resumed and sea ice area has recovered, although internal ocean observations are inadequate for full description of ongoing changes.

Understanding of these processes and the prospects for sea level rise can be improved with the help of more specific knowledge of how the rapid sea level rise in the Eemian occurred. We speculated in our 2016 paper[23] from evidence of a late Eemian shutdown of the AMOC that this may have enhanced Antarctic ice melt and the amplifying feedbacks of SMOC shutdown and sea ice expansion, but this requires improved dating of Eemian events and more realistic modeling.

In 2019 we responded to an unusual opportunity for climate research funding at a level as much as $1.5 million per year for five years. That is the magnitude of the level of support required to assemble a team of world experts to evaluate better what happened in the Eemian and what are the implications for coming decades and centuries. Such a study requires a broad range of expertise that no single group possesses, as indicated by the very title of our preproposal – Aerosols, the Ocean and Ice: Impacts on Future Climate and Sea Level.[24]

Aerosols, for example, are an essential but neglected part of the climate problem including projection of how climate will change in coming decades. Human-made aerosols (fine airborne

particles) cause a climate forcing second only to human-made gases and changes of aerosols are beginning to have a substantial climate effect.[4] We included in our proposal collaboration with colleagues and former students in China, especially on the aerosol component; these co-investigators would be funded independently by their own government. Although the cooperation is justified by their capabilities in observations and analyses, it is worth noting that there is additional merit in the cooperation. Surely successful efforts to mitigate climate change will require cooperation of China and the United States. Our mutual understanding can only be aided by such cooperative scientific studies.

Our pre-proposal two years ago was not successful. It is our intention to seek additional collaborators, make a new proposal from scratch that is more understandable to the non-technical person, and then seek potential funders of the research. Because of the major uncertainties in climate modeling, it is important to include researchers from a few capable modeling groups.

Prior to that, JH will finish his overdue book (Sophie's Planet), which is now possible as the actions and inactions of governments associated with the United Nations COP26 meeting are sufficiently clear. We hope that the book will make clearer the need for the proposed research.

Our organization – Climate Science, Awareness and Solutions – requires funding support for the coming year if we are to be able to continue our work this year and prepare the proposal for longer-term support, so we are repeating below our year-end funding appeal that we appended to last week's communication.[20]

[Sorry, ran out of time to explain how we can keep shorelines near where they are – people are going on vacation after today -- will take up this topic in a later communication and in the book.]

Work status and funding appeal. Some people have asked: what happened to *Sophie's Planet*? After finishing 47 of 50 chapters, I temporarily suspended writing. I wanted to see what President Biden would do in his first year in office and what well-hyped COP26 would produce. I will write those concluding chapters soon, after I finish work for a couple of science papers.

Government posturing at COP26 was largely hogwash, as I recently described in A Realistic Path to a Bright Future. Global warming has accelerated in the past several years, Earth's energy imbalance has increased dramatically, and the growth rate of greenhouse gases is not slowing – in fact it has increased. The world needs good advice, and I hope that we can contribute to that.

We are grateful for the public support of Climate Science, Awareness and Solutions that we received in the past two years after we lost two of our long-term major funders (Two Gentlemen). This, and matching support from the Grantham Foundation, allowed our program to continue to function. We hope for continuation of such public support for one more year. Please consider a donation to either our CSAS program at Columbia University (which supports Pushker Kharecha – my deputy and expert in carbon cycle and energy – and Makiko Sato – physicist and data expert) or our non-profit CSAS.inc (which supports our communications consultant Eunbi Jeong and our work with attorney Dan Galpern on legal cases aimed at affecting the policies of the fossil fuel industry and governments, and other expenses –

computers, copiers, travel, etc. – without overhead.) CSAS.inc.is advised by a wonderful group of climate experts and advocates including Betsy Taylor (President), Bill McKibben (Vice President), Larry Travis (Treasurer), Jay R. Halfon (Secretary), Jim Miller, and Jeff Sachs. You can learn more about them here.

Contributions to CSAS at Columbia University can be made directly at https://csas.givenow.columbia.edu/#. This is the safest and fastest way to give directly to our Columbia program. Should you still prefer to send a check, please make it **payable to** "The Trustees of Columbia University" and include **a note** on the memo line that the gift is for "Earth Institute's Program on Climate Science, Awareness and Solutions."

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The work we are doing with Dan Galpern on the legal front is equally important as the science. During 2021 I worked closely with Dan in three critical areas: (1) Challenges to domestic and foreign fossil fuel expansion projects, (2) Pressing the Biden Administration and the Environmental Protection Agency (EPA) to adopt an effective decarbonization program, and

(3) Innovations in law and policy to hold the carbon majors accountable for causing or exacerbating Earth's Energy Imbalance.

As for the first area, we assisted, via expert declarations or public communications, in Power River Basin coal mining expansions in Montana, and new off-shore drilling operations in the North Sea, among others. We also prosecuted the State of California and the US Forest Service for their flagrantly damaging clear-cutting of old-growth trees on the western board of Yosemite National Park.

As for the second area, we continue to press the Biden team, including the EPA, to impose a rising carbon fee *under existing statutory authority* to phase-out fossil fuel emissions. Congressional inaction, therefore, is plainly no excuse. *See* the whole story and sign our petition to the President here.

And as for the third, we are now readying another petition *to compel EPA* not only to collect a fee from carbon majors for new emissions, but also pay to remove excess atmospheric CO_2 (and other legacy GHG emissions) for which they are accountable under fundamental common law and statutory principles.

Your support will help us press forward in these three areas, both in the halls of government and in court, during 2022.

The next 10 years – the 4th decade since adoption of the 1992 Framework Convention on Climate Change – will be crucial for getting the world onto a path toward a long-term salubrious climate with reasonably stable shore lines. That is still possible, I am confident. In my opinion, the biggest threat – as you may already have inferred from this document – is the possibility that political polarization in the United States and elsewhere that could make good governance almost impossible. That's why I suggest that young people – and others who support the future of young people – create a 3rd political party in the United States to reduce polarization and promote good governance.

As for our work – which will continue to be in climate science and its implications for policy – the next 10 years are also crucial. During that period – because of inertia and momentum of the climate and energy systems – greenhouse gases and global warming will continue to increase. The error in the fanciful notion that global warming can be kept below 1.5°C (I used other words to describe this in Bright Future[2]) will be obvious, climate impacts will be increasingly apparent, and scientists will need to be prepared to offer good advice.

During 2022 – after *Sophie's Planet* is finished – we will prepare a proposal for long-term research that will help reveal requirements to achieve the goal of a long-term salubrious climate with reasonably stable shorelines. The major part of this will involve analysis of what happened during the prior (Eemian) interglacial period, when global temperature was about the same as today and sea level suddenly (within less than a century) increased several meters, perhaps from collapse of the West Antarctic ice sheet.

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