Foreword: Uncensored science is crucial for global conservation

Editor's Note: This essay by esteemed scientist James Hansen is a hybrid of the books' foreword and an independent treatise on the accelerated warming of the planet.

Science is needed today more than ever

We must follow the science to save our home planet, but what does the science tell us? Essays in this extraordinary work will help scientists communicate their findings to the public and policymakers, which is one objective of conservation scientist Dominick DellaSala, the book's mastermind. The lessons provided—in personal integrity, preparation, accessibility (the elevator speech), alliance-building, and political acumen—have wide applicability.

Science was a guiding force in the explosions of knowledge and political revolutions of the 17th and 18th centuries—the Age of Science and Reason, also called the Enlightenment. Rationalism was spurred by Galileo's telescopic observations. Science dispelled myths, such as the belief that the Sun orbited Earth. Medieval worldviews began to change.

However, there was no sudden global epiphany. Galileo, for his daughter's sake and his own sake, was forced to "confess" his heresy, comforted by the realization that history would provide fair assessment and judgment. A delay in understanding was not harmful to the world.

Today science still competes with beliefs. Yet the need for rationalism in understanding—of both our planet and our political systems—has never been greater. And we do not have the luxury of ample time that Galileo enjoyed.

Philosophers of the Enlightenment were mainly European, but the American Revolution and Constitution were the most important political products that emerged on the world scene. Concepts of freedom, equality, individual rights, and celebration of diversity were at the heart of this first democratic constitutional republican form of government, characterized by the rule of law with the consent of the governed, and by checks and balances among competing interests.

I was born in 1941—the year the United States entered World War II—and grew up in the post-war era, when, unlike the period after World War I, the

United States provided global leadership, supported the reconstruction of war-torn regions, led the formation of the United Nations, and promoted the Universal Declaration of Human Rights. Global cooperation and commerce increased. Standards of living improved in nations adopting constitutional governments with individual rights, including nations defeated in World War II. The United States took the lead in establishing the international organizations that facilitated economic growth and security. Cooperation lifted all boats; it was not a zero-sum game.

When I was a kid, we were taught that America was a shining city on a hill. “Truth, justice and the American way” seemed almost synonymous when the comic hero Superman first uttered that phrase. Science provided a way to discover the truth. The objective scientific method is designed to uncover the unvarnished truth, independent of our preferences.

Presidents Harry Truman and Dwight Eisenhower respected science. Eisenhower had a Science Advisory Committee and he invested in our educational system. Not long before his death, Eisenhower said to James Killian, his former Science Adviser: “You know, Jim, this bunch of scientists was one of the few groups that I encountered in Washington who seemed to be there to help the country and not to help themselves” (Killian, 1977). Eisenhower wanted the truth and the country benefitted from it.

Eisenhower was concerned as he left office in 1960. He saw the growing power of special interests. His farewell address focused on the military-industrial complex, which grew with a perceived threat by the Soviet Union. That threat receded as NASA, formed in 1958, beat the Soviets to the moon, arms control treaties were negotiated, and the Berlin wall was torn down. But, like a cancer, the role of special interests and money in our government continued to grow.

Truth is the enemy of special interests

Gradually, the truth became malleable to politicians. They became elite and addicted to the money of special interests. They justified taking money as being required for their campaigns, but it also supported their lifestyles. Their first priority became their own reelection, not the best interests of the public.

The other party became the focus, the enemy. Negative campaigning worked. The next campaign began the morning after the last election. Bipartisanship waned. Governance and policies suffered. Wealth disparity grew. Opportunity was not equal. Unjustified military adventures abroad drained lives, treasure, and spirit. We did not seem to have a government working to achieve a more perfect union. Frustration of the public brought out the worst from fringe groups, including scapegoating and hatreds. Home and abroad, the public saw that America’s professed idealism—of a shining city on a hill—was becoming a sham. Yet politicians attempted to prove their patriotism by the number of flags in their photo-ops.

We still live in a democracy with enormous potential, but we must work to make it work. The shock of recent events—angry, destructive protests—may be a godsend, if it invigorates the people who believe that we can still achieve a more perfect union. Founders of the American democracy foresaw the sort of deterioration that we have witnessed—corruption, really—and they believed that every so often a revolution may be required to restore government integrity. Not a shooting revolution—they hoped—but a revival of the spirit of public service.

We have reached such a time. I am optimistic that we can find a path out of our present dangerous partisanship. I believe that truth and science can help us find that path.

My perspective derives from a long career in science, including efforts to communicate implications of climate science to the public and politicians. Indeed, the chapters in this book and the world's precarious circumstance—on the cusp of previously only imagined global change—forces me to ponder: where did we go wrong? How could we scientists do a better job of informing the public and policymakers?

My first foray into the world of policy was innocent. I wrote a paper describing research carried out by six other young atmospheric physicists and me at the NASA Goddard Institute for Space Studies (Hansen et al., 1981). We warned that continued business-as-usual fossil fuel use could result in global warming as great as 5°C by the end of the 21st century. Such warming, we noted, might result in disintegration of the West Antarctic ice sheet and sea level rise of as much as several meters by the end of this century, as well as extreme regional climate consequences.

Furthermore, we dared to point out obvious policy implications of our study, writing:

> *Political and economic forces affecting energy use and fuel choice make it unlikely that the CO_2 issue will have a major impact on energy policies until convincing observations of the global warming are in hand. In light of historical evidence that it takes several decades to complete a major change in fuel use, this makes large climate change almost inevitable. However, the degree of warming will depend strongly on the energy growth rate and choice of fuels for the next century. Thus, CO_2 effects on climate may make full exploitation of coal resources undesirable. An appropriate strategy may be to encourage energy conservation and develop alternative energy sources, while using fossil fuels as necessary during the next few decades.*

Funding for our CO_2 research was promptly terminated by the U.S. Department of Energy. The impact was sobering and stressful, as I had to inform individuals that we had lost support for five young scientists. It was clear already in 1981 that special interests had inordinate sway in our government—and no special interest was more powerful than the fossil fuel industry. The funding blow added to pressures to close our Institute in New York and move remaining scientists to Greenbelt, Maryland. We survived in New York thanks to the help of two angels, one at Columbia University and one at Goddard Space Flight Center (Hansen, 2022a).

Funding constraints did not terminate our climate research. In Chapter 3, Sounding the Alarm, Former Assistant Secretary General of the United Nations Franz Baumann points to my 1988 testimony before the Senate Committee on Energy and Natural Resources (Hansen, 1988), when I concluded that "earth is warming by an amount that is too large to be a chance fluctuation and in my opinion the greenhouse effect. . .is changing our climate now." My conclusion was hardly universal then (Kerr, 1989), but I could state it with confidence based on the combination of paleoclimate evidence, global climate models, and ongoing observations of climate change. Altogether, it was clear that a basic change in the world's energy strategy was needed.

Remarkably, within a few years the UN Framework Convention on Climate Change was agreed upon in Rio in 1992 and would be signed by almost all nations. The stated objective of the Framework Convention is "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 timeframe 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" (United Nations Framework Convention on Climate Change, 1992).

The Framework Convention was a political triumph, achieved at a time when the scientific community had barely begun to recognize that greenhouse-driven climate change was underway—as evidenced by the reactions to my Congressional testimony (Kerr, 1989). Yet even three decades later, the Framework Convention has had almost no effect in stemming the growth of atmospheric greenhouse gases. Indeed, after the 1997 Kyoto Protocol, global fossil fuel emissions of CO_2 (Fig. 1), the principal drive of global warming, accelerated faster!

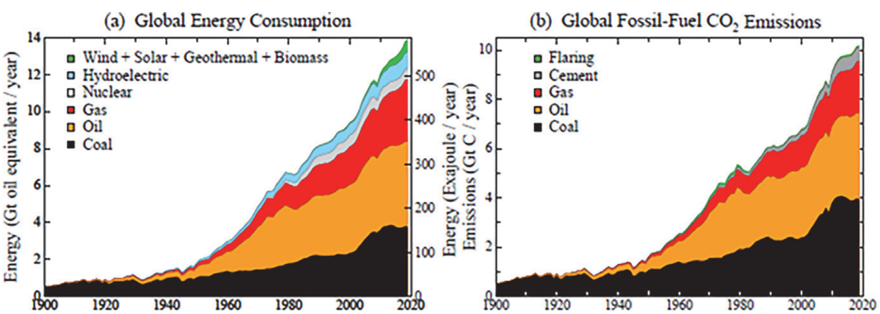

Figure 1
Global energy consumption (A) and fossil fuel CO_2 emissions (B) from 1900 through 2019.

Censorship, as Dominick DellaSala realized in choosing essays for this book, is a problem for conservation

Blatant censorship can be addressed by public objection, but institutional and personal costs discourage such revelation. Moreover, there are also more subtle constraints on communication, which are more difficult to address and may be more dangerous.

In my testimony to Congress I had no intent to be a whistleblower—I just reported science as I saw it. However, when NASA preferred to have someone from Headquarters testify in my stead in 1988, I did not acquiesce because his testimony would differ from mine (Hansen, 2022b). And in 1989 I informed the Senate committee that my written testimony had been altered, over my objection, by the White House Office of Management and Budget (Hansen, 2022c).

After a third incident—I submitted a paper (Hansen et al., 1990) on the need for small satellite observations that were not included in NASA's Earth Observing System—I was reprimanded for "fighting NASA for a third time." I objected, arguing that I acted under allegiance to scientific accuracy and the taxpayers. I took the issue to high levels—the NASA Administrator and the White House (Vice President Al Gore)—but without effect (Hansen, 2022d).

That's not surprising. The problems emanate from the highest levels. The NASA troops—and government employees in other agencies that I interacted with—are hard-working competent people. The problem is that they are constrained to work in an increasingly bureaucratic, inefficient system. Neither political party makes a serious effort to reduce bureaucracy and increase government vitality. On the contrary, both parties have increased the politicization and inefficiency of government agencies.

The political party controlling the executive branch installs political appointees to head Offices of Public Information at science agencies, which thus become Offices of Propaganda that attempt to make the incumbent Administration look good. Both parties allow their Office of Management and Budget to alter scientific testimony. These are fixable problems. The public can affect this situation via political parties, their platforms, and elections—as I discuss below.

Regarding my specific disagreements with NASA, I had to accept the punishments, which included a reduction of resources for the Institute that I headed. I was in love with science and uncomfortable with the hullabaloo that accompanied my testimonies, so I had already decided to retreat into scientific research. I continued to advocate for small satellite measurements but otherwise tried to focus on science and avoid controversy.

By 2004, I felt compelled to speak out again because of growing evidence that we were moving toward dangerous climate change but had no effective policies. Reactions to my talks exposed both continued government censorship and a censorship self-imposed by scientists.

Government censorship was so routine that NASA thought nothing of assigning a minder to screen my interactions with media. When censorship reached the level of "prior restraint"—I was required to tell NASA Public Affairs of interviews beforehand and let them replace me—I informed the New York Times. Prior restraint blatantly violates the Constitutional right of free speech. After a Public Affairs employee confirmed the censorship, the Times published a story that put an end to this specific censorship. NASA pretended that the censorship had been the work of a 24-year-old maverick, but Bowen (2008) in *Censoring Science* found that instructions came from the White House and the highest levels at NASA Headquarters.

When I was asked to testify to Congress again, the Director of Goddard Space Flight Center—whom I greatly respected—gently suggested that I would be wise to stick to climate science and not discuss policy. I could not have agreed less. Why should scientists not connect dots all the way to defining the actions needed to avoid dangerous climate change? If scientists do not speak up, policies will continue on the disastrous course defined by special interests.

Scientific reticence can amount to self-censorship

Indeed, damage from excessive reticence can exceed that from ham-handed government strictures.

In public lectures (Hansen, 2004, 2005a) I argued that the dangerous level of warming is lower than implied in UN Intergovernmental Panel on Climate Change (IPCC) reports. The IPCC "burning embers" method was used to calculate a 50% chance of exceeding the dangerous threshold if global warming reached 2.85°C relative to late 20th century climate or 3.45°C relative to 1880–1920 (Schneider and Mastrandrea, 2005). That comported with common sense: 2°C–3°C warming did not seem to be disastrous.

But paleoclimate data give pause. When Earth was last 3°C warmer—in the Pliocene—sea level reached at least 10–15 m (33–50 feet) higher (Dwyer and Chandler, 2009; Dumitru et al., 2019). IPCC relied on ice sheet models that needed millennia to yield large ice sheet change. The then-current IPCC (2001) report estimated sea level rise of only 40–45 cm by 2100, with 30 cm from thermal expansion of ocean water, 10–15 cm from alpine glaciers, and little change from the ice sheets—for the heavily studied IS92a scenario, which has 715 ppm CO_2 in 2100.

Field geologists who worked on the ice sheets—Konrad Steffen, Eric Rignot, and Jay Zwally—doubted those models. They expected more rapid ice sheet disintegration. So did I. In an editorial essay (Hansen, 2005b), I argued that a warmer ocean and marine-abutting ice sheets could yield a sea level rise of several meters in a century. Human-made climate forcing—imposed perturbation of Earth's energy balance—in IPCC scenarios for this century is larger and much more rapid than natural climate forcings. It seemed nonsensical to think it would take a millennium to achieve a large response.

Scientific reticence (Hansen, 2007) arises partly from the reward structure. A scientist crying danger is rebuked—by fellow scientists and funders—as we learned in the 1980s. But there is no penalty for "fiddling while Rome burns." Indeed, a scientist who lards his conclusions with excessive caveats and uncertainties is rewarded. Caution has merits, but in the case of ice sheets and sea level rise, we may rue reticence, if it locks in future disasters.

Something was wrong with ice sheet models

In fairness to the modelers, ice sheets are complex with processes occurring on a wide range of spatial scales, so modeling ice sheets is hard. However, it is easy to find instances in the paleoclimate record when sea level rose several meters in a century (Fairbanks, 1989; Deschamps et al., 2012). Ice sheet models did not capture such rapid change.

What could we do in the absence of good ice sheet models? Known cases of sea level rising several meters in a century imply exponential ice sheet disintegration, a process characterized by amplifying feedbacks that lead to collapse of a vulnerable portion of an ice sheet. Such a process can be characterized approximately by a doubling time for the rate of ice sheet mass loss.

I decided to do a climate modeling experiment in which—instead of using an ice sheet model—we used the observed rate of ice melt and let it grow exponentially. We would try alternatives—10 years and 20 years, for example—for the doubling time. Precise measurements of ice sheet mass were beginning to be made, so if our concept was right and high emissions continued, we would eventually get an empirical measure of the doubling time.

In October 2006 we—Reto Ruedy, Makiko Sato, and I—made a model run with meltwater injection from Antarctica and Greenland. The initial ice melt rate was from observations; it then increased with a 10-year doubling time up to a sea level rise of 5 m. Most of that water could be provided by West Antarctic ice, which rests on bedrock below sea level (Fig. 2). Deep valley outlets on East Antarctica (Greenbaum et al., 2015) and Greenland (Catania et al., 2020) expose additional ice to contact with ocean water.

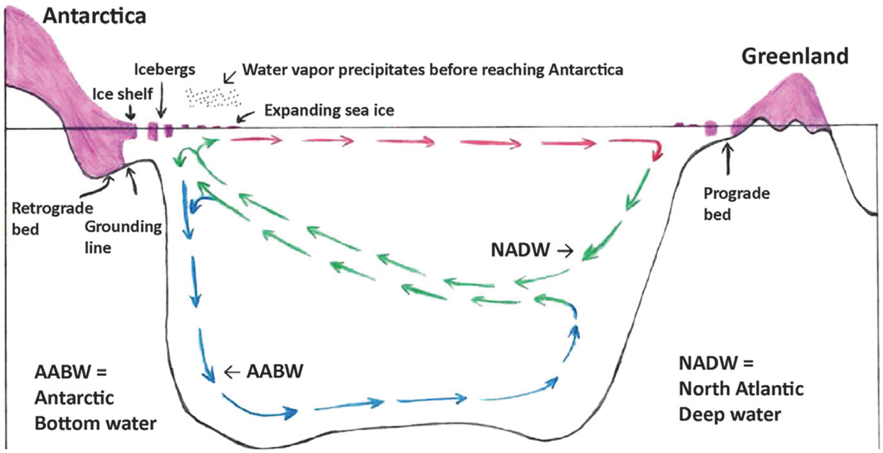

Figure 2 Schematic diagram of the surface origin of two water masses that fill most of the world ocean: North Atlantic Deep Water (NADW) and Antarctic Bottom Water (AABW). The upper circulation cell is the Atlantic Meridional Overturning Circulation (AMOC) and the deeper circulation is the Southern Meridional Overturning Circulation (SMOC). Physical processes occurring near the ice sheets are discussed later in this foreword and this illustration is adapted from Hansen et al. (2016).

I was stunned by the model result

Within several decades the North Atlantic and Southern Ocean Overturning Circulations (dubbed AMOC and SMOC) had shut down. In a hot, warming world, sea ice around Antarctica held steady and then expanded northward!

Wally Broecker had long asserted that ice melt could shut down the AMOC and cause cooling in the North Atlantic and Europe. However, climate modelers did not confirm his expectations. Wally was not a climate modeler. He grumpily acceded to the modelers, but he retained a healthy skepticism of climate models (Hansen, 2022e). I shared Wally's skepticism.

Why did our result differ? Our climate model included an ocean model designed by Gary Russell with special attention to proper conservation of physical quantities. We also included the cooling effect of icebergs in the freshwater discharge from ice sheets. However, our model had coarse resolution compared with other models. We were certain to be hammered by other scientists if we presented new results without a good explanation for why they differed.

Now we were challenging both ice sheet models and ocean models! We had neither a glaciologist nor an oceanographer on our little team. We did not have the heft, nomenclature, or detailed understanding needed to challenge the leaders in those fields. So, we had a lot of work to do. Moreover, I was committed to protests against government inaction on climate, and I was involved in issues in energy science and economics about how to phase out carbon emissions.

In 2007 I read papers of geologist Paul Hearty and initiated correspondence with him

Hearty explored sites worldwide, focusing on places with minimal vertical movement of Earth's crust from tectonic uplift or crustal rebound caused by ice sheet melt. Hearty's papers (e.g., Hearty and Neumann, 2001; Hearty et al., 2007) are full of photos, maps, and descriptions that allow readers to almost feel that they are accompanying a classical geologist who skillfully reads the record of Earth's climate and sea level imprinted in the rocks.

My interest was in Hearty's conclusion that rapid sea level rise of at least a few meters occurred late in the Eemian interglacial period, raising sea level to +6–9 m (20–30 feet) relative to today. The Eemian is the most recent interglacial period prior to the present (Holocene) interglacial period during which civilization developed. Global temperature during the Eemian was 1°C–2°C warmer than the preindustrial Holocene, thus providing an indication of what may be in store as a consequence of human-made global warming.

Hearty was not alone in concluding that rapid sea level rise occurred in the Eemian. Rohling et al. (2008), via innovative analysis of Red Sea sediment cores, found evidence of sea level changes during the Eemian period. If these oscillations were real sea level change, they implied an average Eemian sea level change rate of more than 1 m per century. His group (Grant et al., 2012) also found that sea level changes lagged Antarctic climate changes by only 100–400 years and lagged Greenland climate changes by 200–400 years.

The paleoclimate sea level changes were in response to climate forcings—imposed changes of Earth's energy imbalance—that were weaker and changed much more slowly than the human-made climate forcings. Yet the paleoclimate forcings produced frequent large, rapid sea level change. The models IPCC relied on failed to produce such realistic, rapid change.

Something was wrong with those models. Of that, I was certain.

Providentially, I was invited to give the Bjerknes lecture at the American Geophysical Union meeting in 2008

In my talk, *Climate Threat to the Planet: Implications for Energy Policy and Intergenerational Justice* (Hansen, 2008), I had 1 hour to describe the climate situation and policy implications.

I had a suspicion about a problem in ocean models. When we doubled atmospheric CO_2, we found that global surface temperature after 100 years had only achieved 60% of its final warming. Could mixing of heat into the ocean really slow down the surface response that much? Such a long delay was not expected by the legendary Jule Charney (Hansen, 2022f).

Prior to my talk, I requested model results from three of the most prominent climate groups, and they generously cooperated. The global temperature response of these models was even slower than in our model! I emphasized this topic in my AGU lecture, hoping to encourage reporting of response functions—how fast global surface temperature responds to a forcing—for all models.

Response function information might spur more focus on ocean mixing and on observations to test the reality of ocean mixing in all models. Such a focus on the key (real world and model) physics is analogous to how Jule Charney focused his famous investigation of climate sensitivity (Charney et al., 1979). Charney would have jumped eagerly on the issue of ocean mixing and climate response time, but he died young, in 1981. We lesser scientists were on our own.

The climate modeling community did not jump on the ocean mixing issue, and I was focused on policy matters, as summarized in communications on my website (Columbia, 2021). But then, in 2010 I saw a paper by Karina von Schuckmann, a German post-doc working in a French oceanographic laboratory. She had the data that I had been waiting for.

Karina von Schuckmann analyzes data from thousands of Argo floats that were distributed around the world ocean during the first decade of this century

Argo floats (Argo, 2021) dive to a 2-km depth, rise to the surface while making measurements, and radio the data to a satellite. Precise ocean temperatures measured by the Argo floats were the data needed to define Earth's energy imbalance. That imbalance is important: it defines how much additional global warming is in the pipeline and it thus informs us about actions needed to stop further global warming.

Accurate determination of Earth's energy imbalance meant that we had two major "knowns" about the climate system, the other being observed global warming in the past century. There are three major unknowns: climate sensitivity to a forcing, the net climate forcing, and the delay of surface temperature change caused by ocean mixing of heat.

Climate sensitivity is constrained by paleoclimate data, which implies a sensitivity near 3°C for doubled CO_2 climate forcing. If we assume that sensitivity, we are left with two knowns and two unknowns—a solvable problem. Much of the climate forcing—that due to greenhouse gases, solar irradiance, and volcanic aerosols—is well known, but the human-made aerosol forcing is unknown. So, the two unknowns are aerosol forcing and ocean mixing.

With Karina's data for 2005–10, we concluded (Hansen et al., 2011) that the aerosol forcing was $-1.7 \pm 0.3\ \mathrm{W/m^2}$. This large forcing is not a surprise to aerosol scientists; it is in the middle of the range that they estimated in IPCC reports. Most of their aerosol climate forcing is the "indirect" effect of aerosols on cloud cover and cloud brightness.

Our paper also confirmed the suspicion that ocean models mixed heat into the deep ocean too efficiently, but it did not tell us why. Did models create an artificial diffusion of heat via their finite differencing approximation of the equations of motion? Did the approximations used to represent mixing on scales smaller than the model's grid cause too much mixing? Did the coarse vertical resolution of ocean models cause excessive downward mixing?

Whatever the reason(s), excessive mixing makes it difficult to maintain a low-density ocean surface layer fed by meltwater. Therefore, SMOC and AMOC shut down more readily in the real world than in models. SMOC is more important than AMOC because SMOC shutdown accelerates Antarctic ice melt and sea level rise. The high sensitivity of SMOC implies that sea level rise could begin to run out of control within the next few decades.

How could we make the sea level threat and its implications clearer?

A persuasive case should include an explanation of the rapid Eemian sea level rise. The Eemian interglacial period—just slightly warmer than today—provides the closest real-world example of our likely near-term future. So—on our 40th wedding anniversary in January 2011—Anniek and I spent 3 days on the island Eleuthera, the Bahamas, where we could examine some of the field sites that Paul Hearty had described.

Hearty provided instructions for us to find the field sites. Giant boulders on a ridge as high as 20 m above today's sea level provided the most spectacular evidence. Fig. 3 shows Anniek standing by a boulder dubbed "the bull" by Hearty. The boulders are "hammer-ringing hard" limestone of age at least several hundred thousand years, but they rest on younger, Eemian-age, soil—the Eemian period lasted from about 130,000 years ago to 118,000 years ago.

The boulders must have been washed up the ridge by powerful storm-driven waves—some even rolled down the opposite side of the ridge—providing evidence of the strength of Eemian storms. Quantitative implications for Eemian

Figure 3 Anniek (height 1.6 m) stands beside one of the boulders that were washed to the top of a coastal ridge of North Eleuthera Island, Bahamas, by waves driven by powerful storms during the Eemian interglacial period.

storms are discussed in Chapter 48 of Sophie's Planet. Here we focus on the more important issue: the rapid rise of global sea level.

Hearty et al. (2007) review data from 15 places around the world for sea level during the Eemian. They conclude that sea level rose early in the Eemian to a level a few meters higher than today. Then late in the Eemian there was rapid additional sea level rise to a level as much as 6–9 m above the present level.

Hearty's geologic evidence indicated that the late-Eemian sea level rise required at most a few centuries, possibly less. Independently, Blanchon et al. (2009) used coral reef "back-stepping" on the Yucatan Peninsula to establish an even tighter time scale. As sea level rises, coral moves their reef building shoreward. From rapid back-stepping of coral in the late Eemian, Blanchon et al. inferred that 2–3 m of sea level rise occurred within several decades.

These data all fit together and made sense. We understood a lot about the causes of glacial–interglacial climate change, as discussed in Chapter 25 of Sophie's Planet (Hansen, 2022g). Milutin Milankovitch, building on hypotheses of 19th-century scientists, proposed in the 1920s that glacial–interglacial climate oscillations are caused by small changes of Earth's orbit and the tilt of Earth's spin axis. James Hays and colleagues confirmed the essence of this orbital theory by showing that climate-driven periodicities in ocean sediment cores matched the periodicities of Earth's orbital changes (Hays et al., 1976).

The facts pointed to a clear conviction: the West Antarctic ice sheet collapsed in the late Eemian. Understanding how the natural climate forcings caused rapid sea level rise has strong implications for our future and needed policies. However, before getting to that climactic story, we need to recognize an age-old sort of censorship that scientists have imposed upon scientists.

Resistance by scientists to scientific discovery is widely acknowledged, even though it clashes with the vision of science as open-minded and unbiased

Barber (1961) notes famous scientists who chaffed bitterly at this resistance and is disappointed that they offer only vague explanations, such as "scientists are human" or "fear of novelty."

Feynman (1986) described resistance that embarrasses physicists. Robert Millikan measured the electron charge in an experiment in which he observed the motion of a charged oil drop in the air. The value he reported was not quite right, and it took years to correct it. Why? When an experimenter's results differed too much from Millikan's, the experimenter would look for reasons that some data points were wrong and eliminate those, thus reporting a result not too different than Millikan's. Thus, only slowly did they inch themselves to the true value.

I believe that the IPCC-led climate research community is slowly—too slowly—inching toward conclusions about climate change that are needed for policy purposes. In my opinion, one of the reasons for this excessive slowness is an unusual form of resistance and censorship imposed by scientists who are respected authorities.

It is not unusual for authorities to disagree with a new conclusion. An example is reaction to my testimony in 1988, when I asserted that human-made global warming was underway and significant. The community did not agree. In a 1-week conference my views were almost universally criticized, as reported by Kerr (1989). Kerr—one of the top science writers in the world—provided insight when he quoted one of the experts as saying "if there were a secret ballot at this meeting on the question, most people would say the greenhouse warming is probably there" and another as saying "what bothers a lot of us is that we have a scientist telling Congress things that we are reluctant to say ourselves."

These differences were open and well reported. There was also time to resolve the differences. Nature would soon provide a clearer picture. There was enough time for governments to change energy policies. I was happy to withdraw from that debate.

Here I describe—via a relevant example—a different sort of resistance and censorship imposed anonymously by senior scientists. I raise this issue because—unlike the Galileo and Millikan cases—delay now does great harm. We can lock in large sea level rise if we do not understand the time scale of the relevant physical processes, the actions that are needed to avoid unacceptable consequences, and the policies needed to achieve good results. Large sea level rise would be practically irreversible on any time scale people care about. Also, if the AMOC shuts down totally, it will take centuries to recover (Hofmann and Rahmstorf, 2009).

Blackballing by grand poohbahs includes both resistance to discovery and censorship

To blackball is to ostracize. Blackballing may not be widespread, but it is relevant to the climate story and many of the chapters of this book. I use our paper Ice Melt, sea level rise, and superstorms (Hansen et al., 2016), hereinafter abbreviated as Ice Melt, as a case in point because it brings out the physics and the poohbahs.

Ice Melt is the paper I wanted to write after we ran the "freshwater" climate simulations in 2006. We had reframed the sea level rise problem, as described by Hansen et al. (2016) and in Chapter 48 of Sophie's Planet (Hansen, 2022h). Reframing seemed natural to me and its merits were demonstrated by the master Henk van de Hulst and related by his protégé Joop Hovenier. The idea is to look at an old problem in a new way, preferably a simpler way that provides physical insight. Hovenier said about van de Hulst's propensity to attack a well-worked problem from scratch "it takes a lot of guts!" (Hansen, 2022i).

The old way in the ice melt problem relied on ice sheet models. The models do not yield much ice melt in a century, although they might inch up from one IPCC report to another. Such small ice melt did not have much effect on overturning ocean circulation in climate models.

Reframing was based on real-world data

Paleoclimate data reveal frequent cases of sea level rise of several meters in a century. When an ice sheet, or part of it, becomes vulnerable because of climate change, the ice sheet contraction is often via rapid ice disintegration. Geologists call these "meltwater pulses." Some meltwater pulses may result from slow ice melt that builds up a lake trapped by the ice sheet until the lake suddenly bursts through. Such large lakes and outbursts occur in the geologic record, but they account for only about 1% of paleoclimate sea level rise (Harrison et al., 2019).

Sea level rise of several meters in a century implies exponential growth of the injection rate of freshwater onto the ocean. Exponential growth can be characterized by a doubling time for the period of rapid disintegration, which lasts until the vulnerable ice begins to be exhausted. Paleoclimate examples of sea level rise of several meters in a century imply a doubling time of no more than 10–20 years, at least for the last few doublings.

Our task is to find the doubling time for the West Antarctic ice sheet if greenhouse gases continue to grow rapidly. We can try alternative 10 and 20-year doubling times and cut off freshwater injection when sea level rise reaches 5 m, thus allowing examination of how the ocean and climate recover from the perturbation. This approach also reveals the freshwater injection rates that yield shutdown of the AMOC and SMOC. This procedure—as opposed to step function meltwater injection—mimics real-world ice sheet disintegration, as a given melt rate is preceded by a slower melt rate.

A climate model study that employs a doubling time for freshwater injection is appropriate because it resembles the real world. A common—but unrealistic—alternative is to compare a control run with no freshwater injection to an experiment with a fixed freshwater injection rate or a specified linearly increasing rate. Ice sheet disintegration is inherently exponential; thus, the appropriate way to determine the ice melt rate required to shut down the AMOC, for example, is with exponential freshwater growth.

A large block of time was needed to write Ice Melt. It had to wait until after our 2-year saga to publish a paper (Hansen et al., 2013) needed for a lawsuit against the government. In early 2014 we reran climate simulations with our latest climate model; results were similar to those in 2006. Still, progress in writing Ice Melt was slow. I had retired from the government to start a program at Columbia University—Climate Science, Awareness and Solutions (CSAS)—but it was difficult and time-consuming to obtain funding to cover the three people working with me.

Late in 2014—during the holidays—I received a message from an angel (Douglas Durst)

Douglas provided a gift to CSAS that—with the one-third match that Jeremy Grantham provided for all donations—would cover our costs for more than 2 years. I could work full time on Ice Melt, with the help of Reto Ruedy, Makiko Sato, and other co-authors. I camped out in my study that winter, with about 25 growing piles of papers on relevant subtopics stacked around the floor.

On June 11, 2015, I submitted Ice Melt to Atmospheric Chemistry and Physics (ACP). I chose ACP because the paper could be published promptly as a discussion paper, if it was accepted by the editors after their cursory review. There the paper would be freely available worldwide while it underwent peer review prior to publication in the print journal ACP. I wanted the paper to be available prior to the Paris COP (Conference of the Parties for the United Nations Framework Convention on Climate Change), which would begin on November 30, 2015.

Our paper outlined overall Eemian climate change. The Eemian interglacial period was initiated by large positive insolation anomalies at the latitude of Northern Hemisphere ice sheets—indeed, the largest Milankovitch (Earth orbital) anomaly of the past 400,000 years—which was sufficient to melt the ice sheets on North America and Eurasia and reduce the size of the Greenland ice sheet such that sea level was a few meters higher than today. By the latter part of the Eemian period, insolation anomalies were negative in the Northern Hemisphere but positive in the Southern Hemisphere. Before Northern Hemisphere ice sheets could grow, the small positive insolation anomaly in the Southern Hemisphere caused the West Antarctic ice sheet to collapse and sea level to rise rapidly.

After Ice Melt was published as a discussion paper on July 23, 2015, the Dursts arranged publicity, including an interview by Fareed Zacharia on Global Public Square on CNN. It was a good opportunity to discuss the threat of global sea level rise and policies needed to avoid that. It was clear that governments had no intent to take effective action, even if it made economic sense. I hoped to add pressure for more meaningful policies, such as carbon fee and dividend.

Referee responses to Ice Melt varied

Referee #1 described it as a "masterwork of scholarly synthesis, modeling virtuosity, and insight, with profound implications." Referee #2—an IPCC contributing author—seemed intent on preventing publication. Referee #3 fell somewhere between #1 and #2. Fortunately, the editor secured a Referee #4, who recommended publication and noted that we made several predictions that could be evaluated later.

The final paper was published in ACP on March 22, 2016. Durst's publicist sent it to the Associated Press writer, Seth Borenstein, who replied: "I sent the paper to a large number of the top climate scientists whose names you would recognize. The responses were near universal in their criticism of it as exaggerated and problematic." The Associated Press did not report on our paper. I thought nothing of it then, because others reported on it (Columbia, 2016).

I saw Borenstein in 2018, after it was clear that researchers in relevant disciplines ignored our paper. It was cited by people concerned about climate change but not by researchers in glaciology, oceanography, or paleoclimatology. Seth explained that the scientists he contacted were the leading scientists and five of the six warned him not to write about our paper.

When the grand poohbahs blackball a paper, others in their fields take the cue. Even when new data support our predictions or other scientists reach conclusions that we already published, that fact is not mentioned. I don't need the citations—that's not the problem. The problem, rather, is that our predicted climate change is vastly different than that of IPCC.

IPCC has turned the world on its head. All their reports claim that sea level rise of several meters in a century is highly unlikely, even with CO_2 reaching more than 700 ppm. We find the opposite. With IPCC business-as-usual scenarios, it is practically certain that we would have a devastating sea level rise this century. People need to understand this situation as soon as possible, while we still have a chance to adopt policies that are essential for conservation.

Prior analyses of ocean circulation focused on AMOC

That focus is understandable. Shutdown of AMOC yields large climate change in the North Atlantic with a downstream impact on Europe. The reduced northward ocean heat transport also warms the Southern Ocean—an interhemispheric "seesaw" effect (Stocker, 1998). However, the research community and IPCC concluded that AMOC would not shut down this century; it would only slow down somewhat more than it has already (IPCC, 2019).

Our conclusions differed dramatically. We found that SMOC is more important than AMOC because of its effect on future sea level rise. For business-as-usual scenarios used by IPCC, we found that SMOC would shut down by mid-century (Fig. 4). AMOC would also shut down this century and would not recover for centuries. Our approach to the problem also differed greatly from

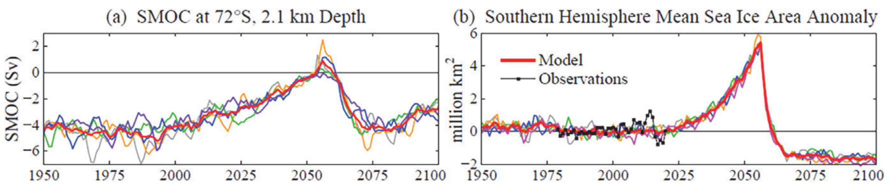

Figure 4 (A) SMOC mean circulation at 72°S (excludes eddy-induced transport), and (B) annual sea ice area anomaly (10^6 km^2) relative to 1979–2000 in five model runs and observations. One Sverdrup (Sv) is 10^6 m^3/s or $\sim 3 \times 10^4$ Gt/year. A Gt is a billion tons. *SMOC*, Southern Meridional Overturning Circulation. *Figure adapted from Hansen, J., Sato, M., Hearty, P., Ruedy, R., Kelley, M., et al., 2016. Ice melt, sea level rise and superstorms: Evidence from paleoclimate data, climate modeling, and modern observations that 2 C global warming could be dangerous. Atmos. Chem. Phys. 16, 3761–3812.*

that of IPCC. While IPCC relies heavily on ice sheet models, our approach was based on empirical information from the real world.

Our climate simulations begin with observed rates of ice melt. Numerous paleoclimate cases of sea level rise by several meters per century imply that the collapse of an ice sheet—once climate change makes it vulnerable—is exponential with a doubling time of at most 1–2 decades. We used a 10-year doubling time for future melt rates in most of the simulations for Ice Melt.

We can obtain an empirical measure of doubling times from continuing observed changes in the masses of the Antarctic and Greenland ice sheets. Data for ice sheet mass loss through April 2021 yield best-fit values for the doubling time of 12, 10, and 7.5 years for Greenland, Antarctica as a whole, and West Antarctica, respectively (Hansen, 2022h). The doubling time for West Antarctica is crucial, because it is expected to be the shortest, in which case it will be the dominant source of global sea level rise later this century.

In our Ice Melt paper—with 10-year doubling times for Greenland and Antarctica—the AMOC shuts down this century (Fig. 5). The high sensitivity of AMOC to freshwater injection that we find in our global climate model is supported by paleoclimate data showing that AMOC shutdowns occurred during interglacial periods when potential freshwater sources were no larger than today (Galaasen et al., 2020).

We sharply terminated freshwater injection onto the ocean when sea level rise reached 5 m in our climate simulations. The purpose was to see how fast AMOC and SMOC would recover once freshwater forcing was removed. We found, in agreement with the expected "hysteresis" behavior of AMOC (Stommel, 1961; Rahmstorf et al., 2005), that AMOC does not fully recover

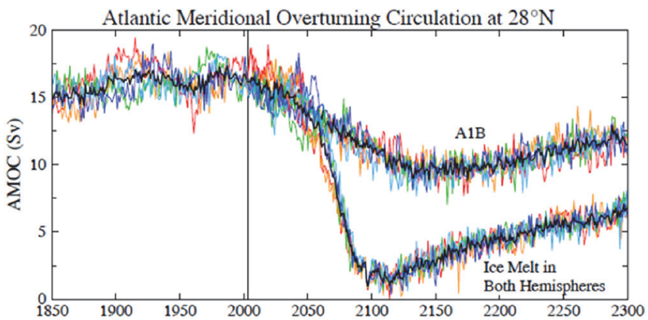

Figure 5 AMOC strength at 28°N in five simulations and their mean (black line) for IPCC A1B scenario and ice melt in both hemispheres, two-thirds of it from Antarctica. *AMOC*, Atlantic Meridional Overturning Circulation. *Figure adapted from Hansen, J., Sato, M., Hearty, P., Ruedy, R., Kelley, M., et al., 2016. Ice melt, sea level rise and superstorms: Evidence from paleoclimate data, climate modeling, and modern observations that 2 C global warming could be dangerous. Atmos. Chem. Phys. 16, 3761–3812.*

even in 200 years (Fig. 5). Furthermore, if ice sheet collapse and multimeter sea level rise occur, freshwater injection is likely to continue for centuries.

How can real-world ice melt be so much faster than in the ice sheet models that IPCC relies on? Ice sheet modeling is hard. Ice sheet processes occur on spatial scales ranging from microscale freeze–thaw effects that cause pot-holes in our streets to continental-scale “rivers” of ice that discharge icebergs to the ocean. However, as argued in my “slippery slope” paper (Hansen, 2005b), the crucial amplifying feedbacks are probably interactions between ice sheets and oceans abutting against them. Our global climate model results in Ice Melt revealed such specific amplifying feedbacks.

Shutdown of SMOC is a powerful feedback

The shutdown can spur the disintegration of the West Antarctic ice sheet (Fig. 2). Our climate model correctly locates deep water formation along the Antarctic coast at places such as the Weddell Sea coast (Section 3.8.5 in Ice Melt), which supports the use of our model to study the SMOC feedback. That capability is absent in many Climate Model Intercomparison Project models used in the IPCC assessment (Heuze et al., 2015).

SMOC already slowed in our climate simulations by the late 20th century (Fig. 4, which is Fig. 32 in Ice Melt) due to growing freshwater injection from Antarctica. Ocean current measurements are too sparse to accurately monitor SMOC, but sufficient for Purkey and Johnson (2012) to conclude that the real-world SMOC did slow during that period.

SMOC is an escape valve for ocean heat. As relatively warm water reaches the surface near Antarctica (see Fig. 2), heat escapes to the air and space—especially in winter. The salty water cools there to high density and sinks, but as increasing light meltwater is added, the rate of sinking water decreases. As this surface escape valve for heat closes, that heat warms the deeper ocean, with maximum warming at 1–2 km depth. That is the depth of ice shelf grounding lines, the part of the ice shelf that exerts the strongest restraining force on landward ice [Fig. 14 of Jenkins and Doake (1991)]. West Antarctic ice shelves thus have begun to melt more rapidly (Rignot and Jacobs, 2002), and the ice streams feeding them have accelerated (Rignot, 2008).

Menviel et al. (2010) used a simplified Earth system model to show that the collapse of the West Antarctic ice sheet would cause expansion of sea ice on the Southern Ocean, suppression of Antarctic Bottom Water formation, and warming of the Southern Ocean at depth. Fogwill et al. (2015) used a high-resolution atmosphere-ocean model to investigate the effects of increasing freshwater flux from West Antarctica today, finding that increased ocean stratification reduced bottom water formation and increased ocean temperature at depth. Fogwill et al. (2015) submitted their paper on almost the same date in 2015 that we submitted our paper. They concluded, however, that they saw no significant atmospheric response to the freshwater injection. We found a significant accompanying atmospheric feedback.

Precipitation feedback is also important

Precipitation provides an amplifying feedback for sea level rise in our model, but a diminishing feedback in the climate models that IPCC has reported and relied on. Their models yield a large reduction of sea ice around Antarctica and increasing snowfall over the continent as Earth warms. This increased snowfall causes sea level to fall, thus at least partially offsetting sea level rise from ice sheet dynamical mass loss (Fig. 2).

In our climate model described in Ice Melt, increasing meltwater cools the Southern Ocean surface enough to offset greenhouse gas warming. Indeed, the sea surface in the western portion of the Southern Ocean, where two-thirds of increased freshwater injection is occurring (Rignot et al., 2013), already has cooled while the rest of the planet has warmed (Fig. 31 in Ice Melt).

If high fossil fuel emissions continue, SMOC will shut down during the next few decades and sea ice in the Southern Ocean will expand several million square kilometers, according to our climate simulations (Fig. 4B). These effects should begin to emerge this decade from the "noise" level of unforced and unpredictable climate variability.

Mother nature threw a curve ball

Before the ink had dried on our Ice Melt paper, the Antarctic sea ice cover plummeted (Fig. 4B) to its lowest level in 40 years of satellite data (Parkinson, 2019). Antarctic Bottom Water (AABW) formation—the engine of SMOC—increased (Silvano et al., 2020). So, was the slowdown of SMOC over the prior few decades only temporary? Will Antarctic sea ice decrease now like Arctic sea ice, as predicted by IPCC models?

No, surely not. On the contrary, data that have accumulated since we submitted our paper in 2015 allow improved assessment of the basic time scales of the climate change problem. These time scales are central to our reframing of the ice melt problem and they are at the heart of our disagreement with the conclusions of IPCC. One merit of our approach is the role of empirical data, which will allow continual, easily understandable, evaluations as climate response unfolds.

Scientists agree that the greenhouse gas amounts in 2100 for business-as-usual assumptions would yield an eventual sea level rise that would be the demise of the world's coastal cities. The disagreement concerns the time scale on which sea level will rise. The most crucial time scale is the characteristic response time for the West Antarctic ice sheet, because West Antarctica contains enough ice to raise sea level a few meters by itself, and its disintegration would be accompanied by substantial contributions from East Antarctica and Greenland.

In Ice Melt we concluded that ice sheets disintegrate faster in the real world than in ice sheet models. In Chapter 48 of Sophie's Planet (Hansen, 2022h) I show that information arising since 2015 supports the suspicion that we voiced in Ice Melt: the real world is more sensitive to freshwater injection than even our climate model suggested.

Those conclusions do not mean that the climate problem is unsolvable. On the contrary, solution of the climate problem makes economic and practical sense—and conservation of nature can be one of many benefits. We are running out of time, however. We cannot afford to waste time on the ineffectual wishful thinking that has characterized past policy efforts.

Let us consider the main threats of climate change, the implications for policy, and the benefits that will accrue from positive action

Sea level rise sets the lowest bar on acceptable global warming. Global temperature by the mid-20th century reached approximately the maximum in the Holocene (Hansen et al., 2017), the current interglacial period in which civilization developed on stable shorelines. We must go back to a global climate no warmer than that of the mid-20th century, perhaps a bit cooler.

Restoration of a moderate global temperature will have many benefits besides saving our shorelines. Global warming has increased the severity of extreme climate events (Hansen et al., 2012), and there is more warming "in the pipeline" without additional increase of greenhouse gases. Climate zones are shifting poleward at a rate much faster than any time in Earth's history that we are aware of. If global warming continues at this rate, much of the low latitudes will become uncomfortable, if not intolerable for human habitation (Raymond et al., 2020).

Emigration pressures arising from climate change are already a global problem, illustrated in recent years by the effects of extended drought in Syria (Wendle, 2015; Kelley et al., 2015) and unprecedented tropical storms in Central America (Kitroeff and Volpe, 2021). Yet these cases pale compared with potential emigration pressures from large sea level rise. A scaling back of global warming is needed to solve these problems.

Extermination of species is another major irreversible effect of uncontrolled climate change. Restoration of mid-20th century climate will alleviate the extinction pressure caused by rapidly shifting climate zones. Other human-caused pressures on biodiversity need to be reduced by means of an increased set-aside of land for nature as covered by DellaSala in the closing chapter 16 of this book. The concept of a contiguous "nature's corridor" stretching through all climate zones of the Americas is described in Sophie's Planet.

We live on a spectacular planet, unrivaled by any other in the universe that we know. With a little more effort in our schools, we can help young people appreciate Earth's wonders and understand that climate change is not something to fear or worry about. Instead, we—and they—have an opportunity and challenge to take actions that will preserve both nature and human-made structures, including our great coastal cities.

We cannot eliminate weather and climate variability, but we can return to a condition in which historic 100-year floods occur only once a century, on average; one in which superstorms and firestorms in populated areas are rare; a planet whose low-latitude regions are not only livable, but able to support the abundant life that was historically adapted to those climate zones.

The challenge is great, but the rewards will be commensurate. We can achieve the goal of restoring and preserving nature's bounty, but only if we are honest about what is required. We must be guided by realistic scientific analysis, not by wishful thinking.

The United States and China must cooperate

The governments of China and the United States are beginning to appreciate the existential threat posed by accelerating global warming. Once they both realize that the climate problem must receive first priority and that solution requires their cooperation, the world can at last begin to address the matter seriously.

There is no point in casting blame, but a quantitative understanding of the cause of climate change is informative. China has the largest fossil fuel emissions now (left side of Fig. 6) and China's energy future will have the greatest impact on climate. However, global warming is proportional to cumulative emissions (Hansen et al., 2007; Matthews et al., 2009), for which the United States is most responsible (right side of Fig. 6). On a per-capita basis, the nations that industrialized early—such as the United Kingdom, Germany, and the United States—will always be far more responsible for climate change than China.

Nations of the West burned fossil fuels to raise their standards of living. There is plenty of fossil fuel in the ground for China, India, Indonesia, and the rest of

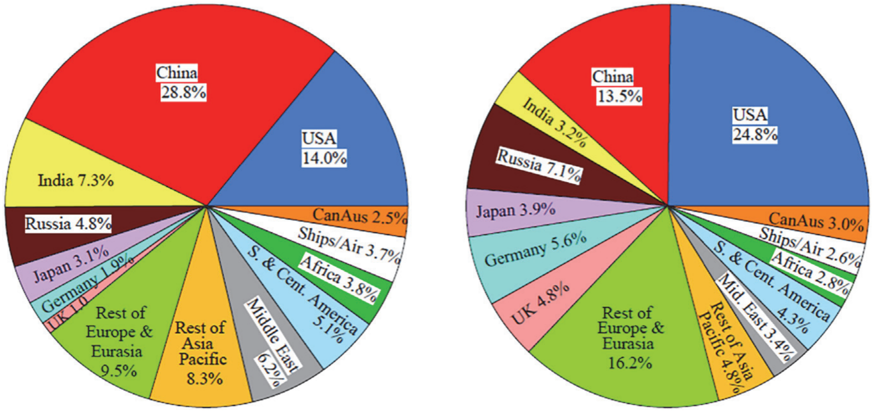

Figure 6 Fossil fuel emissions in 2018 (left) and cumulative 1751–2018 emissions.

the world to rely on for that same purpose, but such a course would assure mutual destruction. We must find a better way.

Robert Daly—Director of the Kissinger Institute on China and the United States—invited me to join him and Ambassador Stapleton Roy in Beijing in 2014 for a Symposium on a New Type of Major Power Relationship (Hansen, 2022j). Topics were climate change and infectious disease. I gave the climate talk, which was blunt, and I provided all of my charts to our Chinese hosts.

My conclusion was that there are two major requirements for solving the climate problem. First is the need for a simple rising carbon (oil, gas, and coal) fee or tax. China and the United States would collect their own fee at their domestic mines and ports of entry. Although each nation would decide how to use the funds, my suggestion was to distribute the money uniformly to citizens, which helps address growing wealth disparities in most nations.

As the dominant economic powers in the world, these two nations can make a carbon fee near-global by imposing a border duty on products from countries without a carbon fee and by rebating the fee to domestic manufacturers on products sold to countries without a fee. Most countries would agree to impose a carbon fee, so that they can collect the money themselves.

The second requirement is a carbon-free alternative to fossil fuels for baseload dispatchable electric power that is as cheap or cheaper than fossil fuels. Such an energy source is a vital complement to renewable energies, even if the latter is used to maximum practical potential.

The final chart in my presentation, updated here as Fig. 7, revealed the sorry state of global efforts to decarbonize energy use. France and Sweden made good progress by using nuclear power for a large portion of their electricity,

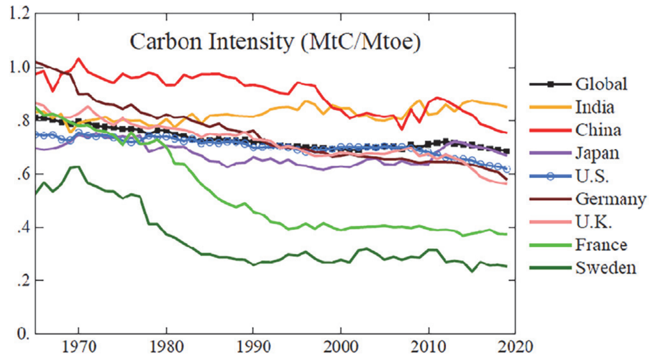

Figure 7 Carbon intensity (carbon per unit energy) of global and national energies. MtC is megatons of carbon. Mtoe is megatons of oil equivalent.

but they stopped short of achieving carbon-free energy for transportation and some industrial processes.

The importance and urgency of the need for inexpensive, carbon-free, baseload electric power cannot be overstated. China and India obtain most of their energy from coal. They will not agree to an equivalent carbon fee until they have a viable alternative to coal, nor should we expect otherwise—all nations will strive to raise their living standards, as the West has done.

Follow the science, not popularism

Science and engineering can help us solve the climate problem, but we are in a race that we must win before either the physical climate system or global governance pass irreversible tipping points. Here I draw attention to "popularism," which is a bias of technical evaluations toward the answer that the audience wants to hear. I give two examples of why this bias is dangerous.

My colleague Pushker Kharecha and I spent years developing our understanding of energy choices and their effects on climate and the environment, including the organization of workshops at the East-West Center in Hawaii and in Washington, as described in Sophie's Planet. Participants included engineers and managers charged with making electrical grids safe and reliable. There was agreement that it is necessary to complement intermittent renewables with reliable, dispatchable power as can be provided by nuclear or fossil energies (Kharecha et al., 2010; Clack et al., 2017; Jenkins et al., 2018).

Nuclear power is the clear preference for climate, and modern nuclear power has the smallest environmental footprint of all energy sources. Even 1970's nuclear technology provided the safest energy during the past half-century in the United States, but there were serious nuclear accidents at Chernobyl, U.S.S.

R. and Fukushima, Japan. Neither of these accidents would have occurred with modern passively safe reactors that shut down in case of an anomaly without need for human intervention or need for external power to keep the nuclear fuel cool.

Modern reactors have the potential to be cheaper than fossil fuels, based on the cost of nuclear fuel and the material required to construct the power plants. However, achievement of that goal requires the same kind of support provided to renewable energies. Utility managers agree that we could already be on the verge of carbon-free electricity if we had adopted clean energy portfolio standards decades ago, rather than renewable portfolio standards.

As a political independent and an agnostic about nuclear power, but concerned about the world we leave for young people, I was distressed to see unscientific origins of bias against nuclear power. As a resident of Pennsylvania, I have been bombarded by specious antinuclear ads paid for and mailed by the American Petroleum Institute (Meyer, 2020). Recent ads focused on nuclear energy subsidies, while in fact, fossil fuels collect the largest absolute subsidies and renewables collect the most on a per unit energy basis. Earlier disinformation focused on nuclear waste. Nuclear waste is small in volume, can be safely stored, and even provide fuel for advanced reactors (Till and Chang, 2011). Fossil fuel waste is dumped in the atmosphere, resulting in air pollution that kills millions of people per year (Kharecha and Hansen, 2013).

Yet there is a danger that fossil fuels will continue to be the main complement to renewable energy. A small number of scientists assert that renewables can soon provide all the world's energy. Liberal media and "big green" environmental organizations (Hansen, 2022k) promote this disinformation, even though authoritative studies conclude that achievement of deep decarbonization of the world's energy by mid-century requires substantial contributions from nuclear power and/or carbon capture and storage. It is a message that the public, most politicians, and the liberal media want to hear. Most informed scientists recognize this as wishful thinking that prolongs the reign of fossil fuels.

Let me give a second example of popularism

We all know that geoengineering is a terrible idea. We do not understand nature well enough that it makes any sense to mess with nature. Oops! We are geoengineering the dickens out of the planet right now! Because of increased greenhouse gases, Earth is out of energy balance, more energy coming in than going out. We are pouring energy into the ocean equal to the energy of 600,000 Hiroshima atomic bombs per day, every day of the year. That heat is ominously melting ice shelves around Antarctica.

The best measure of our geoengineering is Earth's energy imbalance. Changes in the ocean's heat content define about 90% of Earth's energy imbalance.

The main cause of Earth's energy imbalance is the human-made increase of greenhouse gases, with CO_2 from fossil fuel burning being the largest contributor. So, a popular position is that we must stop burning fossil fuels as rapidly as we can, even if it means that we need to stop eating red meat, severely reduce flying, and take other drastic measures.

For sure, we should phase down global fossil fuel emissions rapidly, while we also work to raise living standards globally to reduce poverty. We must find a realistic approach to address the broad needs of global society and conservation.

However, even with maximum effort, atmospheric CO_2 and other greenhouse gases will increase and climate impacts will grow in the near-term. Governments should soon get serious about reducing emissions, but past delay means that more actions are needed. We will also need a good understanding of how we can reduce our geoengineering of the planet.

One widely discussed way to reduce geoengineering is solar radiation management (NAS, 2021). It involves temporary reflection of a small share of solar energy hitting Earth so as to restore Earth's energy balance while the work to eliminate fossil fuel emissions and draw down excess atmospheric greenhouse gases is ongoing.

In October 2018 at the first joint meeting of the American Geophysical Union and the Chinese Academy of Sciences in Xi'an, China, I presented climate simulations in which aerosols were added to the atmosphere with alternative geographical distributions (Hansen, 2018). With aerosols over the Southern Ocean the effect is the opposite of what has been happening in the real world with increasing CO_2. Instead, Antarctic Bottom Water formation around the coast of Antarctica is invigorated, the Southern Oceans cools at the depths of the ice shelves, the ocean surface layer warms, and Earth as a whole begins to cool off.

Research to better understand the climate system and find ways to reduce geoengineering of Earth is warranted, in my opinion. We are likely to reach a point when—despite global efforts to phase out fossil fuel emissions—it is clear that we are headed toward large sea level rise and loss of our coastal cities. Humanity may then wish to consider options such as spraying tiny droplets and cloud condensation nuclei into the air from autonomous floats on the Southern Ocean, with the material being sprayed extracted from the ocean itself. Such aerosols as a tool for conservation are about as natural an approach as one can imagine. They may be capable of restoring Earth's energy balance while we work on reducing atmospheric greenhouse gases.

Yet the popular first reaction to such proposed research is to condemn it, perhaps because it seems unnatural. However, in our efforts to support nature we cannot afford to condemn such research any more than we can simply dismiss the potential and need for advanced nuclear power. In light of the global climate and environmental crises, we instead need to soberly evaluate and weigh the likelihood and range of risks, as we reconstruct a viable future.

President Biden has invigorated the climate issue in the United States

He has assembled experienced and committed advisers, including the United States Special Presidential Envoy for Climate John Kerry and White House National Climate Advisor Gina McCarthy. Their early work is substantial, with President Biden issuing executive orders to reverse the prior Administration's harmful actions, ordering a realistic assessment of the social cost of carbon, and pronouncing accelerated decarbonization targets ahead of the COP 26 meeting (26th Conference of the Parties to the UNFCCC) slated for Glasgow, Scotland in November.

However, the Biden team, in my view, still needs a fair and efficient centerpiece federal climate policy to drive decarbonization across all key U.S. economic sectors. To that end, in January 2021, along with Dan Galpern, my long-time legal and policy adviser, I urged President Biden to impose upstream carbon fees on the major fossil fuel producers, with revenues returned as dividends to citizens. Relying on the scholarship of E. Donald Elliott, formerly the General Counsel of EPA, we argued that the imposition of such fees could be done under existing executive authority (Hansen and Galpern, 2021). If adopted in conjunction with complementary policies under consideration by the Biden team, the imposition of carbon fees would rebuild U.S. international credibility and give us a fighting chance with respect to the climate crisis.

Speaking truth to power: closing thoughts

Science and technology have been a boon for humanity. Standards of living have improved dramatically over the last few centuries for much of the world. Yet as capabilities of our species increased, we also introduced problems, including global climate change.

Science and technology can help solve these problems and allow us to live more in harmony with nature. However, for science to work well it needs to be unfettered by censorship and ideology.

Climate facts are clear. We have passed the dangerous level of atmospheric greenhouse gases. Climate effects of the gases are already detectable and have the potential to cause global chaos if we do not rapidly phase down emissions and take other actions to minimize disruption of nature.

Policy implications are clear. There are three fundamental requirements.

First, we cannot continue to use the atmosphere as a free dumping ground for pollutants from fossil fuel burning. That means that we must have a rising fee or tax on carbon emissions. Such a fee can be readily imposed by the major powers on a practically global basis via border duties on products from countries that do not have an equivalent domestic carbon fee.

Second, clean-energy alternatives cheaper than fossil fuels must be available, including dispatchable (baseload) electric power. Modern passively safe nuclear power appears to be the best option in the near- and medium-term for baseload clean power, but a rising carbon price will allow alternatives such as fusion, carbon capture, and renewables plus energy storage to compete.

Third, we must use the power of ecosystems to sequester and store carbon. Potential carbon drawdown via improved agricultural and forestry practices is substantial, albeit requiring better quantification (Smith et al., 2014: Griscom et al., 2017). We need to protect primary forests, continue growing secondary forests, and reduce emissions from bioenergy (Kun et al., 2020).

So far, the world's nations have taken only baby steps toward the solution of the climate problem, with agreements that amount to wishful thinking, as emissions continue to grow, not decline. Words and goals amount to little, as long as the three fundamental requirements are not met.

When the United States and China realize that they are in the same boat, they may be able to use their combined strengths to move rapidly toward the achievement of the fundamental requirements. Until then, it is good that we have many friends, colleagues, and former students in China. We can cooperate on research that lays the groundwork for future international cooperation (Hansen, 2014).

As chronicled in the essays of this book, we have very little time to change course. Scientists working with advocates need to stand up and be the voice for the planet.

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