# Mind the Gap

*Nadir Jeevanjee, reply by Robert Socolow*

*In response to "A Physicist's Journey" (Vol. 6, No. 3).*

*To the editors*:

The gulf between physics and climate science is a strange one. As Robert Socolow notes in his response to Lawrence Krauss's book *The Physics of Climate Change*, there is a skeptical streak in the physics community regarding climate science. The physicists in that streak question the integrity of climate science and feel deeply uneasy about its reliance on complex, computerized climate models.[1] After expounding some of the basics of climate science, Krauss acknowledges this skepticism when he defends climate science, writing that "much of climate science is not some invisible voodoo practice or something that requires supercomputers to assess."[2]

This skeptical streak resides not at the fringe of physics, but in some of the world's most credentialed physicists, whose résumés boast Ivy League institutions and high-level advisory positions. Their heavyweight skepticism continues to stoke the flames of climate denial.[3] This streak has also, as Socolow notes, stirred up controversy within professional physics societies.[4]

At the same time, there is a history of limited but consequential engagement between the fields. Many leading climate scientists began their graduate careers in physics or a related discipline, only later transitioning to climate science.[5] The voices of those who have made such a transition, including Socolow, echo across the chasm, calling for physicists to engage more deeply with climate science.[6] And some physicists indeed have, including Richard Muller whose skepticism about temperature records compelled him to produce his own datasets, which have now become part of the climate science mainstream.[7] The physics community's interest in climate science is evident, and Krauss's effort is but the latest indicator.

What can be done to bridge this strange divide? I concur with Socolow that in many ways Krauss's book is a good start: an accessible treatment of well-chosen topics in climate science, with a clear-eyed focus on the scientific fundamentals and no real political agenda, even if Krauss cannot help making his political and policy leanings clear. Despite the occasional gaffe,[8] Krauss has done his homework and has an experienced communicator's eye for worthy material. The inclusion of intriguing early climate science history and discussion of the zero-emissions commitment are two examples. The zero-emissions commitment is a particularly noteworthy inclusion as that concept undergirds the notion of a carbon budget, as noted by Socolow, but to my knowledge it has not previously found its way into the popular climate-science literature.

At the same time, *The Physics of Climate Change* might be more successful in bridging the gap had a climate scientist offered to write it. It is the motives of climate scientists, not physicists, that have come under scrutiny, and a book from *within* the climate community, focusing exclusively on the science, might be much more effective in establishing the objectivity of climate science than one written by a physicist. Leading climate scientists have, of course, written for the public, but these books tend to conflate science and politics.[9] They lend scientific credibility to certain policy positions, but leave out the reader who wants an apolitical take on the scientific fundamentals. Krauss is to be commended for identifying and filling this void. It should never have been left open in the first place.

There is also room for more bridges from physics to climate science. Physics is replete with recently minted PhDs who love their field but find their attention drifting from elementary particles and quantum gravity toward more pressing and earthly concerns, just as Socolow's and mine did. But at the moment, there are no programs that seek to harness this talent by providing postdoctoral training in climate science to transitioning physicists—or mathematicians, computer scientists, and so on. These recent PhDs are left to make the switch on their own. Such a program would provide climate science a much-needed infusion of talent as well as cross-pollination of skills and ideas, as argued elsewhere.[10] A related effort could be to house more climate scientists in physics departments. This is typical in the United Kingdom, for instance, but is exceptional in the United States where most climate scientists are found in earth science or atmospheric science departments.

Perhaps the most critical gulf is neither political nor practical, but rather cultural. Climate science is a top-down science par excellence, concerned with the details of a complex, multi-scale system whose emergent phenomena seem to defy pencil-and-paper explanation. The 2021 Nobel Prize in Physics was awarded, in part, to climate scientist Syukuro Manabe, not for profound theorizing or dramatic experiments, but for knowing what to put in and what to leave out in the first credible numerical calculations of Earth's climate sensitivity.[11] Even Krauss, in responding to Socolow's plea for more intuition for the zero-emissions commitment, responds that it just seemed simpler to treat it as an empirical result. And the fundamental equation Krauss presents for the radiative forcing from $CO_2$ is actually an empirical fit to simulation output. Such an emphasis on empiricism, as well as reliance on computer modeling, is anathema to the physicist brought up on spherical cows, Fermi problems, and the Feynman lectures.

Perhaps what is also needed is a true physics of climate change: an understanding of climate science's central results that can be explained on a blackboard, which allows theorists to construct back-of-the-envelope estimates and *mental* models of Earth's climate that might complement those run on supercomputers. The two-box model Socolow yearns for is just one such example. The physicists should join in inventing many more.[12]

**Nadir Jeevanjee**

**Robert Socolow** *replies*:

The tide is turning. I refer to the fraught relationship between significant numbers of physicists and climate scientists. I was educated in physics and keep the company of many climate scientists, and I have long found this relationship disheartening and many of the actions and attitudes of both parties unbecoming. Pockets of ill will persist, but, to many scientists in both camps, the critical importance of accelerating learning about the planet is becoming self-evident. While new, ad hoc initiatives are emerging, there are not yet institutional responses commensurate with the job ahead, and this has become an urgent assignment for today's thought leaders.

My letter extends a string of communications here in *Inference*. Lawrence Krauss wrote a primer on climate science for physicists, *The Physics of Climate Change*, which implicitly calls for physicists to engage more deeply with climate science. I wrote a positive review of Krauss's book for *Inference*. Frankly, I saw *Inference* as a channel to reach some of the influential physicists interested in climate science who have played useful roles as gadflies but have not thus far called for greater physics input. Krauss replied in these pages, supporting my call. And now Nadir Jeevanjee, a physicist turned climate scientist and a generation younger than the professionals who have been dominating the public conversation, has advanced the argument with an astute and well-referenced analysis of some underlying causes for the existing impedance. My comments here are meant to amplify Jeevanjee's message.

Greater engagement from physicists can bring a paradigm shift. I hearken back to the 1960s and 1970s when physicists played important roles in transforming research on energy and the environment. My career shift from particle physics drew inspiration from a National Academy of Sciences month-long summer study in 1969, "Institutions for the Effective Management of the Environment," organized by three physicists: Murray Gell-Mann, Gordon MacDonald, and Marvin Goldberger. All three were members of JASON, an advisory group, still in existence, to the US Department of Defense. Gell-Mann later, as a board member of the MacArthur Foundation, helped create the World Resources Institute and many of the Foundation's environmental programs. MacDonald became one of the three members of the first US Council on Environmental Quality, under President Nixon. Goldberger, along with George Reynolds—both Princeton physics professors at the time—convinced the Princeton administration to create a new environmental center in the School of Engineering and Applied Science and conjured up the new faculty position that became mine. Frank von Hippel and Bob Williams, both physicists of my generation, joined our center and carved out their own research areas in proliferation-resistant nuclear power and solar energy, respectively.

My first research project at Princeton was a field study of energy efficiency in residential buildings. Like quite a few young physicists and engineers, I was astonished at the gap in the formulation of the energy problem, where producing energy was scientists' business, but using energy wasn't. We received tremendous institutional support. The Ford Foundation funded a two-year study of the energy problem, headquartered in Washington, DC, which shifted attention toward energy use—not only for buildings but also for transportation and industry. The American Physical Society authorized a 1974 summer study based in Princeton, "Efficient Use of Energy," which led directly to Arthur Rosenfeld changing fields and creating a world-renowned energy efficiency program at the Lawrence Berkeley National Laboratory, under an Assistant Secretary for Energy and Efficiency at the newly formed Department of Energy (DOE). Insights from this new research community transformed lighting, window coatings, refrigerator insulation, condensing furnaces, building controls, and building construction worldwide.

The climate problem today has striking similarities to the energy problem fifty years ago. As then, standard practices are hiding important questions, and researchers in neighboring disciplines are ready to dive in.

The payoff from an infusion of physics into climate science is conveyed well in a book published earlier this year, *Global Warming Science* by Eli Tziperman. He writes in the preface:

> Much of the study of climate change is based on large-scale complex Earth Systems Models that attempt to simulate

> the ocean, atmosphere, land surface, cryosphere, and biosphere. Yet this book is based on the belief that every one of the relevant subjects can be understood using a simpler framework, employing a fairly straightforward statistical analysis, a simple ordinary differential equation, or a set of basic chemical reactions. Some of the issues are then also demonstrated by analyzing the results of complex climate models.[13]

Every chapter has an example of such simplification. My favorite is presented in Chapter 6: the Stommel model, a salinity-driven two-box model of the Atlantic meridional overturning circulation, which provides insight into the potential for sudden weakening of the Gulf Stream. The dependent variable is flow and the independent variable is the amount of "freshening," or rain onto cold water leading to evaporation from warm water. A tipping point, when the flow reverses, emerges from a single quadratic equation. Tziperman writes:

> The Stommel Model … is by no means a reasonable representation of the actual ocean thermal structure … Observations and realistic climate model simulations are critical tools for us to be able to study and predict present and future climates. But a deeper understanding is often achieved using idealized (toy) models that can be analyzed in depth.[14]

Another productive combination of disparate approaches to climate science is the recent work on the thermal properties of arctic ice led by Yao Lai, an assistant professor in the Geosciences Department at Princeton. Lai became interested in ice dynamics as a graduate student in Howard Stone's fluid mechanics group in the Mechanical and Aerospace Engineering Department of Princeton. A recent publication for which she is the lead author brings together the tabletop experiments that are Stone's forte, tracer-based field campaigns in Greenland conducted by researchers at the Lamont-Doherty Earth Observatory, where Lai was a postdoc, and a newly identified universal scaling law for "hydraulic transmissivity."[15] My own recent paper with Tapio Schneider and Nadir Jeevanjee, "Accelerating Progress in Climate Science," carried a similar endorsement of methodological hybrid vigor, in this instance between machine learning and detailed physical process modeling.[16]

The modalities for fostering new approaches to climate science are similar to those required half a century ago when the supply-focused energy research community needed to turn attention to energy efficiency. Such modalities include

1. Problem-focused blue-sky "summer studies," in which scientists and engineers who have not previously worked in climate science mix it up with veterans.
2. Support from foundations, professional societies, national academies of science, and private individuals for the earliest of these exploratory exercises.
3. Modest expansions of the climate science funded by NASA, the DOE, the National Oceanic and Atmospheric Administration, the National Science Foundation, and similar government agencies in other countries.

The analogy here is with the way the DOE made room for renewable energy and energy efficiency in its national laboratories during the 1970s, even creating what is now the National Renewable Energy Laboratory. Advocates for these and other enabling efforts must take care not to undermine existing climate science, which is a marvel of global cooperation and cutting-edge research at modest scale.

Climate science does not yet clearly pinpoint the precise arrival times of bad outcomes: a meter of sea-level rise or one of many menacing positive feedback loops involving the ocean, clouds, permafrost, forests, and other Earth systems. A broad attack on climate science that includes physicists as well as scientists and engineers in neighboring disciplines can sort out how Earth works, faster than is happening now.

Standing in the way of more ambitious climate science is the excuse that if there is still more to learn about climate science, then delay in addressing climate change is prudent. This profoundly misguided argument must be confronted head-on: what we already know is reason enough to act, and what we do not know makes arguments for action even stronger. Given the stakes, the value of reducing our ignorance is immense.

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1. The first such climate models were developed at the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey, where I work.
2. Lawrence Krauss, Chapter 11, *The Physics of Climate Change* (New York: Post Hill Press, 2021).
3. See, for instance, the book by former California Institute of Technology Provost and Obama administration energy official Steven Koonin, *Unsettled: What Climate Science Tells Us, What It Doesn't, and Why It Matters* (Dallas: BenBella Books, 2021); the op-ed by Princeton physicist and Bush

and Trump administration official Will Happer, "No Need to Panic about Global Warming," *Wall Street Journal*, January 27, 2012; or the cover story on renowned theoretician Freeman Dyson by Nicholas Dawidoff, "The Civic Heretic," *New York Times Magazine*, March 25, 2009.

4. See this account from Gayathri Vaidyanathan, "Physicists Battle over the Meaning of 'Incontrovertible' in Global Warming Fight," *Scientific American*, April 14, 2015.
5. For example: Edward Lorenz (MS, mathematics), Jule Charney (MS, mathematics), Isaac Held (MS, physics), Timothy Noel Palmer (PhD, physics), Chris Bretherton (PhD, mathematics), Raymond T. Pierrehumbert (PhD, aeronautics), Bjorn Stevens (MS, electrical engineering), William Collins (PhD, astrophysics), Geoffrey Vallis (PhD, physics), John Francis Brake Mitchell (PhD, physics), and John Houghton (DPhil, physics).
6. See, for example: Quirin Schiermeier, "Climatologists to Physicists: Your Planet Needs You," *Nature* 520, no. 7,546 (2015): 140–41, doi:10.1038/520140a; John S. Wettlaufer, "Climate Science: An Invitation for Physicists," *Physical Review Letters* 116, no. 15 (2016): 27–28, doi:10.1103/PhysRevLett.116.150002; and Brad Marston, "Looking for New Problems to Solve? Consider the Climate," *Physics* 4, no. 20 (2011), doi:10.1103/physics.4.20.
7. Muller's Berkeley Earth Surface Temperature dataset has been cited in reports by the Intergovernmental Panel on Climate Change (IPCC), such as in Fig. 2.14 in IPCC, *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. Thomas Stocker et al. (Cambridge, UK: Cambridge University Press, 2013). It is also included in compilations of climate data, such as Kevin Cowtan and National Center for Atmospheric Research Staff, eds., "Global Surface Temperatures: Best: Berkeley Earth Surface Temperature," *NCAR: Climate Data Guide* (last modified September 9, 2019).
   Teaching Muller's course "Physics for Future Presidents" while a graduate student at University of California, Berkeley, is what began my own transition into climate science.
8. Earth's effective emission temperature of 255K is misquoted on page 41 as 251K, and on page 47 as 253K. More materially, on page 78, Krauss implies that the surface forcing from $CO_2$ is equal to the top-of-atmosphere forcing, which is not true. See, e.g., Yi Huang, Yan Xia, and Xiaoxiao Tan, "On the Pattern of $CO_2$ Radiative Forcing and Poleward Energy Transport," *JGR Atmospheres* 122, no. 20 (2017): 10,578–93, doi:10.1002/2017JD027221.
9. For example: Michael Mann, *The New Climate War: The Fight to Take Back Our Planet* (Brunswick, Victoria: Scribe Publications, 2021); Michael Mann and Tom Toles, *The Madhouse Effect* (New York: Columbia University Press, 2016); and James Hansen, *Storms of My Grandchildren: The Truth about the Coming Climate Catastrophe and Our Last Chance to Save Humanity* (New York: Bloomsbury, 2010).
10. Tim Palmer, "A Personal Perspective on Modelling the Climate System," *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* 472, no. 2,188 (2016), doi:10.1098/rspa.2015.0772. Palmer, himself having earned a PhD in physics, for many years led the celebrated European Centre for Medium-Range Weather Forecasting. He is now a physics professor in the UK.
11. Heather Hill and Andrew Grant, "Nobel Prize in Physics Honors Research on Climate, Glass, and Other Complex Systems," *Physics Today*, October 5, 2021, doi:10.1063/PT.6.1.20211005a.
12. The views expressed herein are in no sense official positions of the Geophysical Fluid Dynamics Laboratory, the National Oceanic and Atmospheric Administration, or the Department of Commerce.
13. Eli Tziperman, *Global Warming Science: A Quantitative Introduction to Climate Change and its Consequences* (Princeton: Princeton University Press, 2022), xii.
14. Tziperman, *Global Warming Science*, 116.
15. Ching-Yao Lai et al., "Hydraulic Transmissivity Inferred from Ice-Sheet Dynamics following Greenland Supraglacial Lake Drainages," *Nature Communications* 12 (2021), doi:10.1038/s41467-021-24186-6.
16. Tapio Schneider, Nadir Jeevanjee, and Robert Socolow, "Accelerating Progress in Climate Science," *Physics Today* 74, no. 6 (2021), doi:10.1063/PT.3.4772.

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