

if the so-called hockey-stick global temperature reconstruction,² which shows little natural variation, is valid. However, that reconstruction is at odds with natural history and has been shown to be statistically flawed;³ more recent reconstructions^{4,5} show much more natural variation. The fact that general circulation models do not give appreciable Sun–Earth coupling merely shows that they are leaving out essential physics—by no means their only serious shortcoming. Unfortunately, the phenomenological approach of Scafetta and West only informs us of the magnitude of the climatic impact of solar variability. It does not shed light on the actual physical mechanisms, so it points to the need for more research on physical coupling mechanisms between those interacting complex systems.

It is also unfortunate that PHYSICS TODAY chose to feature this work as an Opinion, rather than giving it the full-fledged article status it deserves. The readership should be informed in more detail about this important work.

References

1. N. Scafetta, B. J. West, *Geophys. Res. Lett.* **32**, L18713 (2005), fig. 2.
2. M. E. Mann, P. D. Jones, *Geophys. Res. Lett.* **30**, 1820 (2003).
3. E. J. Wegman, D. W. Scott, Y. H. Said, *Ad Hoc Committee Report on the "Hockey Stick" Global Climate Reconstruction*, Committee on Energy and Commerce, US House of Representatives, Washington, DC (2006), available at http://www.climateaudit.org/pdf/others/07142006_Wegman_Report.pdf.
4. A. Moberg et al., *Nature* **433**, 613 (2005).
5. C. Loehle, *Energy Environ.* **18**, 1049 (2007).

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Scafetta and West reply: The purpose of an opinion piece is to stimulate debate, a function quite different from that of a research paper. However, for this topic, our piece required more than the usual scientific infrastructure to avoid being dismissed out of hand.

The letter writers, whose opinions are all important, tend to fall into three categories: Peter Foukal attempts a scientific critique of our research; Roger Cohen appears to have closely followed our research and has correctly understood its scientific framework; and the other readers do not seem to know the scientific details of the debate and question our work more from a political or ethical perspective. We limit our response to cover those issues we see as crucial.

Diedrich Schmidt argues that our research is politically tainted because it

was partially supported by the US Army Research Office. That charge is as ridiculous as it is insulting. We speculate, without knowing Schmidt, that he would not level the same accusation at scientists reaching conclusions with which he is sympathetic, regardless of the funding source. In America's scientific community, there is freedom to investigate all sides of controversial issues without fear of political pressure from a funding agency.

Claiming that climate is sensitive to solar variability is not a message of despair, in part because solar activity is forecast to decrease during this century. Regardless of what the Sun may do, however, the scientific issue is what matters, and science must have priority over political correctness in this discussion.

Foukal claims that we are neglecting volcanism's contribution to climate change and cites the important work of Gabriele Hegerl and coworkers (see Foukal's reference 2). We did not neglect that effect. The green curve in our figure (page 51 of the Opinion piece) represents the temperature signal after the volcanic signal has been removed using a technique essentially equivalent to that of Hegerl and coworkers but applied to short time scales. The model simulations (blue and red curves), mistakenly interpreted by Wim Klaassen, have two inputs: the phenomenological signature of the 11-year solar cycle on the temperature, obtained after removing the volcanic signal, and a characteristic response of climate to external forcing of about a decadal time scale, which is essentially what many groups' energy balance models assume.

Hegerl and colleagues attempt to interpret some paleoclimate temperature reconstructions from AD 1000 to AD 2000 by means of a simple multilinear regression analysis constructor, which is essentially a linear fit of more than one variable to the data; in their fit are four components: the Sun, volcanoes, a greenhouse gas plus aerosol component labeled as anthropogenic, and noise (see their equation 2 and table 2). The multilinear fitting coefficients, as expected, strongly depend on the particular paleoclimate temperature reconstruction that is adopted.

A careful reader of that table would notice that for some paleoclimate temperature reconstruction, the fitting parameter referring to the solar forcing is negative. That means that if the paleoclimate temperature data and the model of Hegerl and coauthors are correct, every time the solar irradiance increases, the climate cools, and every

time the solar irradiance decreases, the climate warms. That looks quite unphysical. At the other extreme, if another paleoclimate temperature reconstruction is adopted,¹ the multilinear fits give very different results according to the time period fitted, and the anthropogenic component vanishes when the temperature record is fitted from the years 1001 to 1925.

One crucial difficulty surrounding the climate change issue is the huge uncertainty in the paleoclimate temperature and solar reconstruction data and in the climatic effect of the forcing. For example, according to the 2007 Intergovernmental Panel on Climate Change (IPCC) report, a doubling of carbon dioxide would increase the global temperature between 1.5 K and 4.5 K—not a small range. The uncertainty makes quite problematic the application of the traditional climate model methodology, since it relies on having correct data and sensitivities and on knowing the correct physical mechanisms. Unfortunately, those data, sensitivities, and knowledge are not currently available.

For example, when the traditional climate model simulations are compared with the patterns observed in the temperature data, models significantly underestimate the solar signature: The 11-year solar cycle signature on the surface temperature has a peak-to-trough amplitude of 0.1 K, while the climate models predict an amplitude of 0.035 K (see the Goddard Institute for Space Studies ModelE simulations at <http://www.giss.nasa.gov/tools/modelE>). Thus the models appear to be missing important solar–climate linking mechanisms.

Arguing, as Foukal does, that the total solar irradiance and UV radiation do not have enough power to explain the strength of the link suggests that the physics of the solar–climate linking mechanisms should be further investigated, not that the mechanisms do not exist. To think otherwise would be a logical fallacy of scientific reductionism.

As Cohen correctly observes, one major reason the scientific community has believed that most global warming was anthropogenic is the so-called hockey-stick global temperature reconstruction,² which is based mostly on tree-ring data. It shows little preindustrial climate variability and significant warming since 1900. That pattern supports the theory of manmade global warming.^{2,3} However, the latest studies have shown the limitation of the tree-ring temperature reconstructions and that, on the contrary, climate varied

substantially in preindustrial times.^{2,4} The variability suggests that climate is strongly sensitive to solar change and more weakly sensitive to anthropogenic emissions than presently estimated. Thus our research and several new findings appear to indicate that the IPCC's conclusions need significant revision.

References

1. A. Moberg et al., *Nature* **433**, 613 (2005).
2. M. E. Mann, R. S. Bradley, M. K. Hughes, *Nature* **392**, 779 (1998); *Geo. Res. Lett.* **26**, 759 (1999).
3. T. J. Crowley, *Science* **289**, 270 (2000).
4. C. Loehle, *Energy Environ.* **18**, 1049 (2007).

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Constraining potential bomb builders

According to Alisa Carrigan's Opinion piece, "Learning to Build the Bomb" (PHYSICS TODAY, December 2007, page 54), to prevent proliferation of nuclear weapons, knowledge of nuclear power should be kept from scientists and engineers of potentially rogue countries. I would like to comment on her line of reasoning.

First, nuclear weapons are not the only threats to world peace. Chemical and biological weapons are as dangerous as nuclear weapons. So the restriction should not be limited to nuclear physics and related areas of knowledge; various fields in chemistry, chemical engineering, pharmaceutical and biological sciences, physics, and mechanics must also be off limits. After that come certain fields of mathematics—for example, number theory—and software engineering because they have applications in cryptography. Just imagine some terrorist hacking into a computer that is controlling, for instance, airplane traffic. Even quantum computation is dangerous because it has applications in deciphering. Where should one stop?

Carrigan distinguishes between explicit and tacit knowledge. But there is no permanent sharp line between the two. For example, Carrigan mentions the need to use fabric gloves to assemble centrifuges; since that information

has now been published, it has been transformed from tacit to explicit. Since people have access to explicit knowledge through books and journals, it is not sufficient to monitor the sources of tacit knowledge. To prevent proliferation of the required knowledge, the flow of explicit knowledge must be controlled as well. That requires establishing a system of censorship.

I think the logical consequence of accepting Carrigan's idea is a kind of "knowledge nonproliferation treaty." Such a system, if implemented, simply means that people are divided into two categories: those who have the knowledge of making nuclear, chemical, and biological weapons and those who do not. The first category, by this system, has the right and responsibility to block the second group's access to the required knowledge and technology. I think that is simply a variant of apartheid. It would force people in the second category—the "have-nots"—to invoke dirty tricks to get that knowledge. Scientific apartheid doesn't work and is not a suitable means to establish a sustainable peace.

Today, contrary to, say, 100 years ago, even people in developing countries have access to the basics of the scientific method and the fundamentals of science. From those foundations it is, in principle, possible to produce the forbidden knowledge, just as scientists in the developed countries have done. So a knowledge nonproliferation treaty does not help. Because knowledge is not only transported but also produced, it is now almost impossible to impose a knowledge blockade.

Let us consider that problem from another point of view. The case of South Africa's nuclear program is worth discussing. Why did South Africa make weapons and then destroy them? I think the answer is that four decades ago South Africa was having trouble with its neighbors—and with its own people as well. After the apartheid era, the troubles being greatly diminished, South African officials no longer saw the need for nuclear weapons.

Which other countries have made nuclear weapons? North Korea, because of its standoff with South Korea; Israel, because of trouble with all its neighbors; Pakistan and India, because of their long-standing animosity. Carrigan points out that all those nations were able to obtain the required knowledge, and from nonmilitary activities. My conclusion is that if some nation has enough motivation to build a dangerous weapon, it probably can obtain the

knowledge to do so. If we want to build a sustainable peace, why not try to reduce the nations' motivation to have weapons?

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Carrigan replies: Ahmad Shariati makes several valid points in his letter, but most of them are not logical extrapolations from my argument.

For example, he writes that any branch of science or mathematics could be implicated in the process of building nuclear, biological, chemical, or conventional weapons or of hacking into computer systems. That is true: Whatever can be used can be misused, and every branch of science is therefore potentially at risk of being hijacked for malevolent purposes.

Shariati thinks that condition must necessarily lead to a "knowledge nonproliferation treaty" to keep the people that do not possess knowledge to create nuclear, biological, or chemical weapons from obtaining it. But that is in direct contrast to my own conclusions. I wrote, and still believe, that "it is unlikely that the international community can stop the dissemination of nuclear weapons knowledge altogether," or stop the spread of any other type of scientific knowledge. My research indicated that a driven state will find ways to acquire the tacit and explicit knowledge it needs. For precisely that reason I proposed not a knowledge nonproliferation treaty but several steps that might help the international community better track the spread of nuclear weapons knowledge and thereby have a better understanding of who is working on what.

On Shariati's final question, I agree most completely. Attempting to stop proliferation is simply treating a symptom; the disease itself—the political and security drivers motivating states to acquire nuclear weapons—must also be addressed. But I think it is wise to treat both the symptom and the disease simultaneously, especially in this case. I am well aware that nonproliferation policies do not present a final solution to the problem of nuclear weapons, but I also believe it would be negligent to ignore proliferation entirely to focus on quelling states' desires for nuclear weapons.

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