

remained undiminished throughout his life, and he honed his skill as a drummer by joining a jazz trio that played regularly throughout greater Washington, D. C.

Paul devoted nearly as much energy to advancing the infrastructure of Earth science as he did pursuing his own research. He served as the president of the AGU Seismology Section and as chairman of the boards of both UNAVCO and the Incorporated Research Institutions for Seismology. He was a leader in proposing, more than a decade ago, the concept of a plate boundary observatory of seismic and geodetic

instruments across western North America to monitor time-dependent deformation along major fault zones in unprecedented detail. Thanks in no small part to Paul's efforts, that facility now is operational as part of the EarthScope project of the U.S. National Science Foundation.

Paul was elected a Fellow of the American Academy of Arts and Sciences in 2007, and he was the Royal Astronomical Society Harold Jeffreys Lecturer in 2005. He was also a Fellow of AGU and the Geological Society of America and a member of Phi Beta Kappa.

Paul is survived by his wife, Nathalie, of North Bethesda, Md.; his daughter, Karen Silver, of Baltimore, Md.; and his two sisters, Ellen Silver, of Santa Rosa, Calif., and Lauren Silver, of Indianola, Wash. He is deeply missed by his family, friends, and all of those who were touched and inspired by his creativity, his energy, and his exuberance.

—SEAN C. SOLOMON, Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D. C.; E-mail: scs@dtm.ciw.edu

## FORUM

### Climate Change: The Need to Consider Human Forcings Besides Greenhouse Gases

PAGE 413

Humans are recognized as having a major role in influencing environmental variability and change, including their influence on the climate system. To advance scientists' understanding of the role of humans within the climate system, there remains a need to resolve which of the following three hypotheses is correct:

**Hypothesis 1:** Human influence on climate variability and change is of minimal importance, and natural causes dominate climate variations and changes on all time scales. In coming decades, the human influence will continue to be minimal.

**Hypothesis 2a:** Although the natural causes of climate variations and changes are undoubtedly important, the human influences are significant and involve a diverse range of first-order climate forcings, including, but not limited to, the human input of carbon dioxide (CO<sub>2</sub>). Most, if not all, of these human influences on regional and global climate will continue to be of concern during the coming decades.

**Hypothesis 2b:** Although the natural causes of climate variations and changes are undoubtedly important, the human influences are significant and are dominated by the emissions into the atmosphere of greenhouse gases, the most important of which is CO<sub>2</sub>. The adverse impact of these gases on regional and global climate constitutes the primary climate issue for the coming decades.

These hypotheses are mutually exclusive. Thus, the accumulated evidence can only provide support for one of these hypotheses. The question is which one?

Hypotheses 2a and 2b are two different oppositional views to hypothesis 1. Hypotheses 2a and 2b both agree that human impacts on climate variations and changes are significant. They differ, however, with respect to which human climate forcings are important. Because hypothesis 1 is not well

supported, our scientific view is that human impacts do play a significant role within the climate system. Further, we suggest that the evidence in the peer-reviewed literature (e.g., as summarized by National Research Council (NRC) [2005]) is predominantly in support of hypothesis 2a, in that a diverse range of first-order human climate forcings have been identified.

We therefore conclude that hypothesis 2a is better supported than hypothesis 2b, which is a policy that focuses on modulating carbon emissions. Hypothesis 2b as a framework to mitigate climate change will neglect the diversity of other, important first-order human climate forcings that also can have adverse effects on the climate system. We urge that these other climate forcings should also be considered with respect to mitigation and adaptation policies.

#### *Recognizing Other Important Human Climate Forcings*

In addition to greenhouse gas emissions, other first-order human climate forcings are important to understanding the future behavior of Earth's climate. These forcings are spatially heterogeneous and include the effect of aerosols on clouds and associated precipitation [e.g., Rosenfeld et al., 2008], the influence of aerosol deposition (e.g., black carbon (soot) [Flanner et al. 2007] and reactive nitrogen [Galloway et al., 2004]), and the role of changes in land use/land cover [e.g., Takata et al., 2009]. Among their effects is their role in altering atmospheric and ocean circulation features away from what they would be in the natural climate system [NRC, 2005]. As with CO<sub>2</sub>, the lengths of time that they affect the climate are estimated to be on multidecadal time scales and longer.

Therefore, the cost-benefit analyses regarding the mitigation of CO<sub>2</sub> and other greenhouse gases need to be considered along with the other human climate

forcings in a broader environmental context, as well as with respect to their role in the climate system. Because hypothesis 2a is the one best supported by the evidence, policies focused on controlling the emissions of greenhouse gases must necessarily be supported by complementary policies focused on other first-order climate forcings. The issues that society faces related to these other forcings include the increasing demands of the human population, urbanization, changes in the natural landscape and land management, long-term weather variability and change, animal and insect dynamics, industrial and vehicular emissions, and so forth. All of these issues interact with and feed back upon each other. The impact on water quality and water quantity, for example, is a critically important societal concern. The water cycle is among the most significant components of the climate system and involves, for example, cloud radiation, ice albedo, and land use feedbacks [NRC, 2003]. Regional and local variations in water availability, water quality, and hydrologic extremes (floods and droughts) affect humans most directly.

If communities are to become more resilient to the entire spectrum of possible environmental and social variability and change [Vörösmarty et al., 2000], scientists must properly assess the vulnerabilities and risks associated with the choices made by modern society and anticipate the demands for resources several decades into the future. Moreover, since the climate, as a complex nonlinear system, is subject to abrupt changes and driven by competing positive and negative feedbacks with largely unknown thresholds [Rial et al., 2004], scientists' ability to make skillful multidecadal climate predictions becomes much more complicated, if not impractical.

#### *Resource-Focused Risk Assessments Should Complement Global and Regional Predictions*

Risk assessments require regional-scale information. Thus, in addition to the current approach based on global climate models, local and regional resource-based foci are needed to assess the spectrum of future risks to the environment and to the resources required for society. For example,

by regulating development in floodplains or in hurricane storm surge coastal locations, effective adaptation strategies can be achieved regardless of how climate changes.

We therefore propose that one should not rely solely on prediction as the primary policy approach to assess the potential impact of future regional and global climate variability and change. Instead, we suggest that integrated assessments within the framework of vulnerability, with an emphasis on risk assessment and disaster prevention, offer a complementary approach [Kabat *et al.*, 2004]. This should be conducted in parallel with attempts to improve skill in predicting regional and global climate on multidecadal time scales. This leads to a practical and sensible way forward that will permit a more effective climate policy by focusing on the assessment of adaptation and mitigation strategies that can reduce the vulnerability of all of our important societal and environmental resources (involving water, food, energy, and human and ecosystem health) to both natural and human-caused climate variability and change.

#### *The Need for a Broader Approach*

The evidence predominantly suggests that humans are significantly altering the global environment, and thus climate, in a variety of diverse ways beyond the effects of human emissions of greenhouse gases, including CO<sub>2</sub>. Unfortunately, the 2007 Intergovernmental Panel on Climate Change (IPCC) assessment did not sufficiently acknowledge the importance of these other human climate forcings in altering regional and global climate and their effects on predictability at the regional scale. It also placed too much emphasis on average global forcing from a limited set of human climate forcings. Further, it devised a mitigation strategy based on global model predictions. For example,

although aerosols were considered as a global average forcing, their local effects were neglected (e.g., biomass burning, dust from land use/land cover management and change, soot from inefficient combustion).

Because global climate models do not accurately simulate (or even include) several of these other first-order human climate forcings, policy makers must be made aware of the inability of the current generation of models to accurately forecast regional climate risks to resources on multidecadal time scales. For example, how the water cycle responds to the diversity of climate forcings at the regional level will be important information to policy makers seeking to mitigate risks to water resources.

We recommend that the next assessment phase of the IPCC (and other such assessments) broaden its perspective to include all of the human climate forcings. It should also adopt a complementary and precautionary resource-based assessment of the vulnerability of critical resources (those affecting water, food, energy, and human and ecosystem health) to environmental variability and change of all types. This should include, but not be limited to, the effects due to all of the natural and human-caused climate variations and changes.

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—ROGER PIELKE SR., University of Colorado, Boulder; E-mail: pielkesr@ciresmail.colorado.edu; KEITH BEVEN, Lancaster University, Lancaster, UK; GUY BRASSEUR and JACK CALVERT, National Center for Atmospheric Research, Boulder, Colo.; MOUSTAFA CHAHINE, Jet Propulsion Laboratory, California Institute of Technology, Pasadena; RUSSELL R. DICKERSON, University of Maryland, College Park; DARA ENTEKHABI, Massachusetts Institute of Technology, Cambridge; EFI FOULOULA-GEORGIU, University of Minnesota, Minneapolis; HOSHIN GUPTA, University of Arizona, Tucson; VIJAY GUPTA, University of Colorado; WITOLD KRAJEWSKI, University of Iowa, Iowa City; E. PHILIP KRIDER, University of Arizona; WILLIAM K. M. LAU, NASA, Greenbelt, Md.; JEFF McDONNELL, Oregon State University, Corvallis; WILLIAM ROSSOW, City College of New York, New York; JOHN SCHAAKE, U.S. National Oceanic and Atmospheric Administration, Silver Spring, Md.; JAMES SMITH, Princeton University, Princeton, N. J.; SOROOSH SOROOSHIAN, University of California, Irvine; and ERIC WOOD, Princeton University

## LETTER

### Comment on “Developing and Implementing an Effective Public Outreach Program”

PAGE 413

J. A. Harrison *et al.* (*Eos*, *90*(38), 333–334, 22 September 2009) provide a laudable overview of scientific outreach and the steps required to support a robust public outreach effort. However, it is unfortunate that issues related to energy were

absent from the profiled list of outreach resources. Energy issues unite geoscience disciplines ranging from rock mechanics to atmospheric kinetics. Furthermore, energy issues make up a large and important part of the public discourse about economic recovery, security, and environmental protection. To promote scientific

literacy across a range of energy topics, many professional societies have organized outreach programs: the Society of Petroleum Engineers' Energy4Me program, the American Wind Energy Association's wind energy curriculum, and the American Association of Petroleum Geologists' extensive geoscience education program. Researchers should consider availing themselves of these resources to support their outreach activities and integrate energy education into their programs.

—SAMUEL C. SCHON, Department of Geological Sciences, Brown University, Providence, R. I.; E-mail: samuel\_schon@brown.edu