FORUM

Earth Science in the Anthropocene: New Epoch, New Paradigm, New Responsibilities

We live in the Anthropocene: For better or for worse, the Earth system now functions in ways unpredictable without understanding how human systems function and how they interact with and control Earth system processes. Regardless of whether this transition from the Holocene (generally thought of as the past 12,000 years) to the new epoch of the Anthropocene will ultimately be for the better or for the worse, the Earth system will not be returning to a preanthropogenic state for the foreseeable future.

Human involvement in the Earth system has now gone far beyond mere interference with "natural" processes. Human systems have emerged as new primary Earth systems, not only by dramatically altering preexisting natural processes but also, more important, by introducing a host of new Earth system processes entirely novel to the Earth system. As a result, the classic paradigm of "Earth systems with humans disturbing them" is obsolete. Human systems have become as integral and defining a component of this planet's processes as are biological, atmospheric, hydrologic, and geologic systems. As with the rise of photosynthetic organisms and the emergence of the biosphere, human systems have driven the Earth along a new and unprecedented path.

With this in mind, Earth science needs to be rebuilt on a new foundation, one in which human systems are as much a part of Earth systems as is the biosphere or the atmosphere.

Earth Science Research and Education Must Be Rebuilt on a "Postnatural" Paradigm

Earth systems science cannot progress without a new paradigm that includes human systems and processes as primary components, drivers, and constraints on Earth system processes at the same levels as those of the lithosphere, atmosphere, hydrosphere, and biosphere.

At this point, you might be thinking, "Human systems are not really Earth science." Human systems don't seem different in terms of just discipline, like geophysics versus biogeochemistry; they seem different in kind—not a part of Earth science at all. But at its heart, this way of thinking seems no different from the initial hesitancy of geoscientists to embrace biological processes as fundamental Earth systems processes, as important as geology or atmospheric science. Still, human systems have yet to be properly incorporated into Earth science either as a geophysical "sphere" (the "anthroposphere") or as a set of well-defined geophysical processes. Yet some necessary elements of a postnatural Earth science paradigm are clear:

• *Human systems emerge from human interactions.* As individuals, or even populations, we humans are just another species. However, human systems represent the integrated effects of humans interacting with each other at scales capable of forcing changes in the atmosphere, lithosphere, biosphere, and other Earth systems. Just as anthills are more than the sum of their ants, human systems are more than the sum of human individuals. For example, the Earth now glows at night. This new earthlight is not the sum of individual human actions but is a societal activity fueled by burning fossil carbon to drive complex electrical systems. This exemplifies just how far human systems have gone beyond the biological and are now forcing the Earth system in new directions, in this case by driving the rapid combustion and atmospheric release of fossil carbon that is now warming the planet at unprecedented rates.

• *Human systems processes are of two kinds:* those that have long occurred without humans but are now profoundly altered by humans and those that have emerged along with human systems. Novel human systems processes include the unearthing and combustion of fossilized photosynthates; the directed evolution of species unable to reproduce without humans; and the regular tillage, irrigation, and nutrient subsidy of soils. Human systems have also enhanced preexisting processes by orders of magnitude, including the burning of forests and other vegetation, species extinctions, soil erosion, hydrologic impoundment, and nitrogen fixation.

• *Human systems interact directly with other Earth systems in both directions.* Human systems drive and constrain biogeophysical processes, and they also respond to these processes. For example, human systems both drive climate change and are affected by climate change, just as biospheric changes alter climate and are affected by climate change.

• *Human systems include sapient processes.* Though human systems have historically been regulated by external biogeophysical processes such as climate, and by self-regulatory processes resembling homeostatic feedbacks such as the regulation of human population growth by disease, they are increasingly exhibiting signs of self-regulation by intelligent processes acting to control both human systems and external Earth systems. Witness the rapid rise and decline of chlorofluorocarbons and photochemical smogs.

As a discipline, Earth science has now passed beyond its traditional question, "How do Earth systems work?" We are now regularly called to answer questions like, "What will happen to Earth's climate if we continue adding carbon at current rates?" and even, "How can we keep the planet habitable for humans?"

Geoscientists are ever more actively involved in geoengineering to counter global warming by injecting sulfate aerosols into the stratosphere, industrial carbon sequestration, and other massive technological alterations of Earth systems. Grand proposals for ocean fertilization, orbiting mirrors, genetically engineered biofuels, painting rooftops white, cloud-generating ships, and the like all point toward the future of Earth science as an applied discipline with the human future in the balance. Humans long ago reengineered most of the biosphere to support agricultural production. If we are ultimately called on to directly manage climate, storms, rivers, and other major Earth systems, this will only increase human responsibility for the current and future state of Earth systems.

A Personal Oath for Earth Scientists?

Sir Joseph Rotblat, a physicist and the winner of the 1995 Nobel Peace Prize, once said that "the time has come to formulate guidelines for the ethical conduct of scientists, perhaps in the form of a voluntary Hippocratic Oath." Given that members of our profession are now regularly in the position of advising decision makers on how to manage Earth systems with the future of humanity in the balance, we propose that our discipline administer, upon obtaining the Ph.D. in Earth or environmental science, an "Oath for Earth Scientists," promising adherence to a set of guiding principles such as the following:

• That we must always make clear to the public that our scientific understanding of Earth systems is limited and that therefore there are inherent risks to altering Earth systems whether by intentional or unintentional action.

• That we must always describe the specific risks (as far as we understand them) to all Earth systems, including human systems, from the implementation of any specific scheme to alter an Earth system.

• That whatever advice we give, we give for the benefit of humanity, remaining free of intentional distortion or personal bias.

The hope is that by publicly adopting this professional oath, we may be more influential in guiding the public, our decision makers, and our students toward more successful management of human systems, the only Earth systems that truly pose a serious threat to the future of humanity.

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Geophysicists

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the Detection of Atmospheric Composition Change; and an expanding role for NOAA personnel in the leadership of some of these global observing networks. Dave understood the value of these measurements for important scientific and societal issues, and he was a strong proponent of making the science of atmospheric change accessible to laypeople. He was instrumental in developing NOAA's annual greenhouse gas index as well as NOAA's annual ozone depletion index, as tools to enhance the connection between scientists and society. Dave was awarded the Department of Commerce's Silver Medal for creating the greenhouse gas index.

After retiring as director in 2007, Dave returned to scientific analysis and hands-on research, his first love. His latest work appears in two papers published just before his death. These papers provide a new analysis of atmospheric carbon dioxide and an evaluation of recent stratospheric aerosol measurements from the Mauna Loa and Boulder lidars. The latter paper showed once again that the stratospheric aerosol is far from static and that there needs to be attention focused on understanding the changes that may occur due to the impact of anthropogenic activities. While it is possible that Dave may have reflected on the similarities of his latest work with some of his earliest work—both focused on new facets of stratospheric aerosol—it is more likely that he was already planning his next analysis.

Dave thoroughly enjoyed his work and highly valued his colleagues and workmates. His contributions, generous spirit, wisdom, and humor will be sorely missed. Dave is survived by his partner, Shirley Purcell, daughters Gretchen and Jennifer, and son Karl.

—Terry Deshler, University of Wyoming, Laramie; E-mail: deshler@uwyo.edu; and James H. Butler, Susan Solomon, John E. Barnes, and Russell C. Schnell, National Oceanic and Atmospheric Administration, Boulder, Colo.