GEOPHYSICISTS

## In Memoriam

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**John W. Firor**, 80, 5 November 2007, Atmospheric Sciences, 1968

**Gunter R. Seckel**, 83, 15 October 2007, Ocean Sciences, 1954

**Mark Tilston**, 57, 26 June 2007, Hydrology, 2005

**Robert E. Wallace**, 89, 8 January 2007, Tectonophysics, 1972

## Honors

**C. Christian Tscherning**, secretary general of the International Association of Geodesy (IAG), was awarded the IAG's 2007 Levallois Medal in recognition of his outstanding contribution to geodesy. The medal, which is normally awarded at 4-year intervals, is given in recognition of distinguished service to the Association and/or to the science of geodesy in general. The medal honors former IAG General Secretary Jean-Jacques Levallois.

# FORUM

## Research Needs for Finely Resolved Fossil Carbon Emissions

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Scientific research on the global carbon cycle has emerged as a high priority in biogeochemistry, climate studies, and global change policy. The emission of carbon dioxide ($CO_2$) from fossil fuel combustion is a dominant driver of the current net carbon fluxes between the land, the oceans, and the atmosphere, and it is a key contributor to the rise in modern radiative forcing. Contrary to a commonly held perception, our quantitative knowledge about these emissions is insufficient to satisfy current scientific and policy needs. A more highly spatially and temporally resolved quantification of the social and economic drivers of fossil fuel combustion, and the resulting $CO_2$ emissions, is essential to supporting scientific and policy progress. In this article, a new community of emissions researchers called the $CO_2$ Fossil Fuel Emission Effort ($CO_2$FFEE) outlines a research agenda to meet the need for improved fossil fuel $CO_2$ emissions information and solicits comment from the scientific community and research agencies.

Compared with other aspects of the carbon cycle, fossil fuel $CO_2$ emissions appear to be relatively well understood. In the industrialized world, nation-level $CO_2$ emissions have been quantified at annual and sometimes monthly timescales, often by sector (residential, commercial, and so forth) and fuel type (coal, oil, and so forth). However, in many parts of the world, only annual, nation-level totals are quantified, and these totals often contain uncertainties as large as 100%. Many countries with large uncertainties are among the world's top $CO_2$ emitters and are increasing their emissions at unprecedented rates.

In the past, $CO_2$ emissions from fossil fuel burning at spatial scales smaller than nation level were derived by downscaling to a uniform grid (currently $1^\circ \times 1^\circ$) using population density (determined by census reports or by nighttime lights satellite imagery) as a spatial proxy. This proxy-based emissions inventory has been used widely in a variety of scientific research in biogeochemistry and climate science, and it has been crucial to advancing scientific understanding in those research arenas. However, to answer today's scientific questions and assist policy makers, fine-scale estimates of carbon emissions, based on the processes creating them (e.g., electricity generation, home heating, vehicle propulsion), must replace emissions estimates that are based on population-related proxy variables. The reasons for such a process-based fine-scale carbon emissions database are threefold.

First, the coarse, proxy-based approach taken in the past has inherent errors that can generate significant bias, particularly as demand for information at finer scales grows. For example, industrialized countries contain large $CO_2$-emitting electricity-generating facilities that are often located far from population centers. Similarly, large interstate highways traverse areas with low population but may host dense truck traffic. Hence, $CO_2$ emissions and population density are often not coincident in space.

Second, there is a rapidly growing need in both the science and policy communities for much finer spatial and temporal resolution of fossil fuel $CO_2$ emissions information and for a much better quantification of the underlying processes. For example, the atmospheric inverse approach to quantifying biospheric $CO_2$ exchange will soon be assimilating data from the Orbital Carbon Observatory (OCO), a NASA satellite expected to launch in December 2008. The high-resolution satellite data (<10 kilometers) will enable the inverse method to quantify carbon exchange at much finer spatial scales than are currently possible, given the sparse network of in situ observations. Because fossil fuel $CO_2$ emissions are central to inverse carbon flux estimation, these emissions must be at a commensurate scale in space and time.

Third, a process-based fossil fuel $CO_2$ model-data system can form the basis for more realistic emissions projections for climate change scenarios. Such a system would include information on population demographics and urban growth patterns; infrastructure and technologies (energy systems, industrial growth); social variables such as affluence, culture, and behavior; climate change and energy use patterns; economics of energy availability and prices; and policy models of the evolving regulation landscape.

The needs of policy makers, regulators, and the public to assess and mitigate greenhouse gas emissions place new demands on this work. Building emissions inventories driven by the dynamic processes that generate these emissions provides the connection between decisions and the resulting emitted quantities. These processes would identify the sector and subsector of the economy producing the emissions, and could also include economic dimensions such as fuel prices, technology penetration, and tax or trade elements. With such detailed information, governments could develop more effective and informed policy, and the business community could target cost-saving approaches for improving efficiency while reducing greenhouse gas emissions.

In the same way that large-scale biogeochemical modeling moved from simple parameterizations to complex, process-based algorithms, fossil fuel emissions must progress from simple inventories to process-driven systems that incorporate the physical and socioeconomic dimensions of what, when, where, why, and how fossil fuel $CO_2$ is emitted. An endeavor of such breadth and depth will require a new collaboration between climatologists, engineers, economists, social scientists, and policy analysts.

In the past 5 years, several independent research initiatives have been launched that are aimed at providing more spatiotemporal detail for current emissions in North America. One of these initiatives, Vulcan, named after the Roman god of fire, is a multi-institutional effort (Purdue University, Lawrence Berkeley National Laboratory, Colorado State University) supported by NASA to generate a fossil fuel $CO_2$ inventory for North America at fine space and time scales (http://www.purdue.edu/eas/carbon/vulcan.html). This project, which began in 2005, is nearing completion, and a spatial scale of 10 square kilometers and an hourly temporal scale have been achieved. Similar efforts focused on power production and mobile emissions are ongoing at NOAA, and a city-scale effort has been successfully completed by researchers at the University of California, Irvine, for Salt Lake City, Utah. Researchers at the University of Maryland and Oak Ridge National Laboratory currently are quantifying province-level fossil fuel $CO_2$ emissions for East Asian countries emitting the greatest amounts.

To amplify these initial collaborative efforts, access to unavailable data and new funding opportunities are essential to building and verifying emissions estimates. A first step toward identifying research needs and priorities was taken on 23–24 April 2007 when a group of researchers met at the High Resolution Fossil Fuel Emissions Workshop at Purdue University, West Lafayette, Indiana, to specify needs and goals and to strategize collaboration. To support these aims in an ongoing fashion, the workshop attendees formed the $CO_2$FFEE community. The goals of $CO_2$FFEE are to facilitate capacity and information sharing in order to build and integrate the different components of a high-resolution fossil fuel $CO_2$ emissions accounting model-data system. The temporal and spatial resolutions targeted are hourly emissions aggregated over a few square kilometers.

During the 2-day Purdue workshop, the $CO_2$FFEE group identified key needs and research priorities:

• *Access to all relevant existing fossil fuel use data (e.g., local fuel sales, utility bills).* Most of these data exist, but access to the data sets is often restricted. Removing such roadblocks requires forging new partnerships between universities, national laboratories, industrial facilities, energy providers, and local and national governments.

• *Multidisciplinary and interdisciplinary needs.* The process-based model proposed for contemporary and future emissions accounting should include such components as land use and population demography models, infrastructure and technology scenarios, climate feedbacks, energy availability and prices, regulations, and social measures such as affluence and cultural patterns. Such a model should be an integral part of a complete Earth system model and will require new intellectual partnerships and collaboration.

• *Evaluation.* Bottom-up and top-down independent evaluation is essential in order to quantify uncertainty and identify gaps. The first version of a U.S. contemporary inventory of high-resolution fossil fuel $CO_2$ emissions will be released early in 2008 (http://www.purdue.edu/eas/carbon/vulcan.html). To evaluate the inventory, the community proposes local to regional campaigns with two elements: (1) A multicity inventory intercomparison of sectoral emissions and their seasonal cycles would provide independent evaluation of the methods and results. This intercomparison (with cities to be determined) would give the community a better understanding of how urban form and development patterns affect fuel use and emissions. (2) Atmospheric measurements and modeling are powerful evaluation tools and should include measurements of radiocarbon and stable carbon isotopes in ambient air, radiocarbon analyses of vegetation, and $CO_2$ and other pollutant species (e.g., carbon monoxide and nitrogen oxides) from towers, aircraft, and satellite platforms (particularly in urban plumes). Such measurements must be combined with high-resolution transport modeling in order to properly compare atmospheric measurements with inventory estimates.

Though the project is at the very early stages, workshop organizer and host Kevin Gurney (Purdue University) and numerous collaborators have begun outlining what will be required to fulfill the larger global vision described here. This project, called Hestia™ (named for the Greek goddess of the hearth), envisions building a model-data system that will produce fine-scale $CO_2$ emissions and their driving processes on a framework similar to Google Earth™ with the goal of meeting the needs of all the scientific and policy-making goals described here. Such an effort will require significant computing resources, multi-institutional research, multinational cooperation, and a large array of disciplinary expertise and funding support.

To take the next steps, the needs laid out in this Forum need to become a priority for research agencies and governments at state, national, and international levels. Cooperation is required across national boundaries and across the public/private boundary within individual nations. Quantification and process understanding of global fossil fuel $CO_2$ at fine scales are central to understanding where we are now and where we must go in order to carefully, transparently, and efficiently meet the challenges of climate change.

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