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Michael R. Raupach talks with *ScienceWatch.com* and answers a few questions about this month's Emerging Research Front Paper in the field of Environment/Ecology.

Article: Global and regional drivers of accelerating CO2 emissions
Authors: Raupach, MR;Marland, G;Ciais, P;Le Quere, C;Canadell, JG; Klepper, G;Field, CB
Journal: PROC NAT ACAD SCI USA, 104 (24): 10288-10293 JUN 12 2007
Addresses: Commonwealth Sci & Ind Res Org, Global Carbon Project, Canberra, ACT 2601, Australia.
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(addresses have been truncated.)

SW: Why do you think your paper is highly cited?

This paper made five contributions, each of which contributed to its high citation rate.

First, it showed that the annual growth rate of CO_2 emissions from fossil fuels accelerated since 2000 to well over 3% per year, a large increase above the growth rate in the 1990s (just over 1% per year) and well above the long-term historic growth rate, over two centuries, of just under 2% per year.

Second, the paper compared observed growth rates in emissions to scenario predictions made around 2000 in the Special Report on Emissions Scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC), showing that actual emissions growth rates lie well above average growth rates for all six SRES scenario families.

Third, the paper showed that the drivers of increasing emissions over the last several decades were approximately equally partitioned at global scale between growth in population and growth in per-capita Gross World Product (GWP), offset by improvement in the carbon intensity of the global economy—but the recent post-2000 increase in emissions growth rate was driven mainly by increased growth in GWP.

Fourth, the paper identified a decrease in the rate of improvement in the carbon intensity of the global economy in the first few years following 2000, which made an additional contribution to the increased

emissions growth rate.

Finally, the paper analyzed the regional contributions to these trends, showing the dominant roles of developing regions and China in particular.

The paper received significant press comment because of the massive interest and policy significance of trends in CO_2 emissions as drivers of climate change, and the implications of current trends for the task of reducing emissions. An acceleration in emissions makes the task of mitigation that much harder. These factors contributed to its high citation rate in subsequent papers analyzing the global mitigation challenge.

This work was an initial contribution to a series of updates of the state and trends of the global carbon cycle, including both natural and human factors, by the Global Carbon Project (GCP) of the Earth System Science Partnership. Companion papers focus on the overall atmospheric CO_2 budget (Canadell, *et al.,* 2007, Le Quere, *et al.* 2009).

"A new and fundamental challenge for science (and society) in this century will be to understand the nature of these limits, and to identify and follow the pathways in which humanity can develop which are consistent with the finite nature of our planet."

SW: Does it describe a new discovery, methodology, or synthesis of knowledge?

The paper was among the first to point out the rapid recent acceleration in human perturbation of the global carbon cycle. It synthesized the human, economic, and technological drivers of CO_2 emissions using basic metrics: population, GWP (or its domestic equivalent) per person, the energy intensity of GWP, and the carbon intensity of energy.

The methods were very simple, involving an algebraic identity called the Kaya identity (Kaya and Yokobori, 1997) which expresses emissions as the product of these four metrics. The Kaya identity is an algebraic truism, but nevertheless provides a useful decomposition of emissions drivers in a form which enables diagnosis of underlying trends. This enables a synthesis of drivers of CO_2 emissions drivers and the responses of the earth system, a theme initiated in this paper and developed in later work (Raupach *et al.*, 2008, Canadell *et al.,* 2009).

The resulting synthesis opened a path for a number of subsequent analyses, which led, in turn, to new evaluations of requirements for climate policies.

SW: Would you summarize the significance of your paper in layman's terms?

CO_2 emissions are rising, faster than most estimates from a few years ago. Every region is contributing to this. Relative emissions growth in developing regions is faster than in developed (rich) regions, but both energy use and CO_2 emissions per person in developing regions are much less than in developed regions.

There are close relationships between wealth, energy use, and CO_2 emissions, which are showing no signs of changing, also changes in these relationships (particularly the amount of CO_2 emitted per dollar of wealth generated) are essential if global wealth generation is to continue while emissions are reduced to reduce the risks of adverse impacts from climate change.

SW: How did you become involved in this research and were any particular problems encountered

along the way?

I started my scientific career as a biophysical scientist, working on fluid mechanics in atmospheric boundary layers and on the exchanges of carbon, energy, water, and other entities between land surfaces and the atmosphere.

My work was first focused at small scales, such as vegetation canopies and small areas of land. Searching for interactions in the biophysical world, I have been drawn to study progressively larger environmental systems including the global carbon cycle and the interactions between the carbon, climate, and human societies.

The inclusion of humans is necessary to understand the way Earth's system works in the present "Anthropocene" epoch, in which human activities are significantly altering the cycles of carbon, energy, water, and other entities, with implications for climate and ecosystems everywhere. The research in this paper and related work with colleagues are steps in this evolution.

There have been challenges, before, during, and since the work reported in this paper.

First, the work is strongly transdisciplinary and requires a synthesis of insights from the natural sciences, economics, and the social sciences. Concepts and worldviews vary widely across this spectrum, as do narratives and languages. The task of understanding is therefore challenging.

Second, work on carbon-climate-human interactions is subject to high media interest and scrutiny. This is so because of direct policy implications, for example for emissions mitigation, and also for deeper reasons associated with the contrasting demands of economic growth and global environmental stewardship.

Third, the trends examined in this paper are changing rapidly and the picture needs regular updating, for example to assess the effects of the global financial crisis (Le Quere *et al.,* 2009).

SW: Where do you see your research leading in the future?

Work on carbon-climate-human interactions, for which this paper forms one quantitative foundation, will merge with work in other disciplines which contribute to the study of what could be called the ecology of a finite planet.

This is the new ecology confronting humankind in the Anthropocene epoch where human activities are altering the dynamics of the Earth's system, and consequently where the natural world imposes limits on human activities through resource constraints and the finite biogeochemical capacity of the Earth.

A new and fundamental challenge for science (and society) in this century will be to understand the nature of these limits, and to identify and follow the pathways in which humanity can develop which are consistent with the finite nature of our planet.

SW: Do you foresee any social or political implications for your research?

There are profound implications, as indicated in all preceding sections.

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PDF

back to top

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