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A RECORD YEAR

2008 went down as the coolest year of the current decade, if still the tenth warmest since instrumental measurements began in 1850. But the past 12 months have done little to cool concerns over the forecast for climate change. If anything, the science that has emerged this year paints a far bleaker picture than the landmark reports released in 2007 from the Intergovernmental Panel on Climate Change.

The latest in a slew of convictions against greenhouse gas emissions, this year scientists for the first time attributed the major changes occurring in physical and biological systems throughout the globe — from early onset of spring to trends in ice melting — to human-caused climate change (page 4). But while conservationists are wrangling with how best to minimize the existing impacts for species and ecosystems, many of the trends are set to gain speed.

Speaking at the 2008 Fall meeting of the American Geophysical Union, which ran from 15–19 December in San Francisco, scientists issued stark warnings along with their latest results. Their models show that, in California, extreme events such as heat-waves now occurring once every 100 years could be happening every year within a century. But even the latest science has failed to predict some of the impacts that are now being witnessed first-hand by scientists, from the accelerated loss of Arctic summer sea-ice to the extensive release of gaseous methane from formerly frozen deposits off the Siberian coast.

The warming caused by carbon dioxide emissions is the chief culprit behind these changes, but other greenhouse gases are now making their presence felt. Most worrying perhaps has been the surge early this year in atmospheric concentrations of methane, a gas with a warming potential twenty-three times that of carbon dioxide. Having maintained a largely constant atmospheric concentration over the past decade, the recent spike in methane remains a mystery and is especially worrisome given the changes occurring in the Arctic. Also on the rise is nitrogen trifluoride, a gas produced in the manufacture of gadgets such as MP3 players and flat-screen TVs. Scientists discovered this year that atmospheric concentrations of the gas have increased 20-fold over the past three decades, yet its emissions remain unregulated.

Although there has been rapid progress in our understanding of the climate system, many questions remain unanswered (page 5). Some of these are issues of attribution such as whether storms will worsen in a warming world. For others the underlying science is settled, but the speed of change remains uncertain. The picture that is now emerging is daunting, but the headway being made in climate science is also encouraging. Only with a robust knowledge of the science can society make informed decisions about how best to respond to the changes underway and the challenges that lie ahead.

OLIVE HEFFERNAN, EDITOR

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RESEARCH HIGHLIGHTS

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ATMOSPHERIC SCIENCE

Methane mystery

ISTOCKPHOTO.COM / CINOBY

Geophys. Res. Lett. **35,** L22805 (2008)

Atmospheric levels of the potent greenhouse gas methane rose sharply in early 2007, having remained largely stable over the past decade. Methane is released from wetlands and wildfires as well as from human activities, such as fossil fuel use and farming, but is destroyed in the atmosphere when it reacts with a compound known as the hydroxyl radical.

Now Matthew Rigby of the Massachusetts Institute of Technology and colleagues have examined the change in global emissions of methane over a ten year period. They retrieved atmospheric measurements of methane and other chemical compounds from two monitoring networks with a total of 12 worldwide locations. Methane levels have risen simultaneously across all global sites since early 2007. The team propose that the increase may have coincided with a slight decline in levels of the hydroxyl radical, but the changes in hydroxyl chemistry alone were insufficient to explain the entire methane rise.

By combining the data with numerical simulations from an atmospheric transport and chemistry model, they were able to attribute the methane spike to a worldwide rise in emissions between 2006 and 2007, the bulk of which originated in the Northern Hemisphere. The exact source of the extra methane, however, remains a mystery.

Alicia Newton

MITIGATION

Facing the future

Global Change Biol. **14,** 2910–2922 (2008)

The influence of elevated atmospheric CO_2 on soil's ability to store carbon is a matter of great debate, with some studies reporting increases in soil organic matter — and hence carbon storage — and others, no change or even a loss. Now, a nine-year investigation suggests that increased litterfall could enhance soil carbon storage in a greenhouse world.

John Lichter of Bowdoin College, Maine, and colleagues examined the effect of CO_2 enrichment on soil carbon sequestration in a loblolly pine plantation. The forest, one of many Free Air CO_2 Enrichment (FACE) experiments across the globe, was exposed to elevated CO_2 concentrations — 200 microlitres per litre above ambient levels — between 1996 and 2005. During this time, the forest floor accumulated an extra 30 grams of carbon per square metre per year. This build up of soil carbon could not be attributed to a decrease in the decomposition of organic matter and was probably the result of increased litterfall.

Although this represents a noteworthy increase in forest carbon storage, it is still small relative to human emissions, say the authors. However, with the first generation of FACE facilities set to close, the sustainability of this carbon sink will remain a mystery for a long time to come.

Anna Armstrong

JOHN LICHTER

CRYOSPHERE

Thinning out

Geophys. Res. Lett. **35,** L22503 (2008)

High elevation glaciers in the Himalayas release meltwater into the Indus, Ganges and Brahmaputra Rivers, contributing up to half of their total river flow. A new study suggests that these glaciers may be thinning, endangering water resources in one of the most populous regions of the world.

Natalie Kehrwald of Ohio State University and colleagues collected ice cores from the summit of Naimona'nyi Glacier in Tibet. The team measured the level of

ISTOCKPHOTO.COM / DAVID CIEMNY

beta radioactivity and the concentration of two radioactive isotopes, chlorine-36 and hydrogen-3, in the ice. These isotopes are common signatures of nuclear weapons testing in the 1950s and 1960s. The notable absence of any radioactive signal in the cores, together with negligible concentrations of radioactive isotopes, indicates that the glacier has had no ice deposited since the 1950s; lead dating confirmed this finding. The authors suggest that increased ice melt resulting from recent warming may be responsible.

Current estimates of the impact of Himalayan glacial retreat on water resources have failed to account for high elevation glacial thinning. If Naimona'nyi is characteristic of other glaciers in the region, meltwater supply is likely to shrink much faster than currently predicted, with considerable negative consequences for up to half a billion people.

Anna Armstrong

ANTHROPOGENIC CHANGE

Double trouble

MATT STRUEBIG

Conservation Biol. doi:10.1111/j.1523-1739.2008.01096.x (2008)

Replacing tropical rainforests with oil palm plantations threatens biodiversity and efforts to reduce greenhouse gas emissions, report scientists. One of a number of biofuel crops touted as a sustainable, environmentally friendly energy source, palm oil now covers some 13 million hectares of land surface worldwide, mostly in Southeast Asia.

An international team of researchers, led by Finn Danielsen of Denmark's Nordic Agency for Development and Ecology, has carried out the most comprehensive analysis yet of the impact of oil palm plantations on tropical forests. They estimate it would take 75 to 93 years for the carbon saved through the use of biofuels to compensate for the carbon lost through clearing tropical rainforest. This payback time would increase to more than 600 years if the original habitat was peatland, and would decrease to just 10 years on degraded grassland, they say. Based on a meta-analysis of faunal data and a comparative field study of flora on forested and converted land in Indonesia, they also show that plantations support species-poor communities compared to forests, and that the most abundant species in converted lands are generalists of low conservation value.

The authors call for global standards to assess the sustainability of biofuel crops.

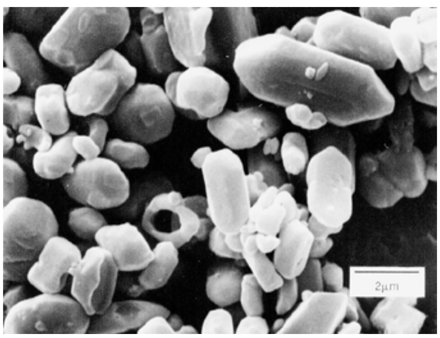
Olive Heffernan

PALEOCLIMATE

Calcium connection

Science **322,** 1671–1674 (2008)

Scientists have uncovered evidence that oceanic calcium concentrations have fluctuated widely over the past 28 million years. The concentration of marine calcium has important implications for ocean alkalinity and for the absorption and storage of atmospheric carbon dioxide in the deep sea.



ADINA PAYTAN

Previous efforts to understand the calcium cycle based on ratios of different isotopes or forms of calcium in marine carbonates, have been hampered by changes in environmental conditions in the ocean that also affect the ratios. To avoid this artefact, Elizabeth Griffith of Stanford University, California, and colleagues turned to tiny crystals of barite, a sulphur-based mineral formed in sea water. They measured the ratio of calcium isotopes trapped in the crystals, which is believed to be unaffected by environmental variability. The group found that the amount of dissolved calcium in the oceans — as well as the isotopic composition of that calcium — has varied dramatically during the past 28 million years.

The most pronounced change occurred 13 million years ago, as the climate cooled and Antarctic ice sheets began to increase. The discovery that marine calcium concentrations have been unstable over long geological periods represents a considerable advance in the understanding of global biochemical cycles, which form a crucial component of the climate system.

Alicia Newton

BIODIVERSITY AND ECOLOGY

Bad news for bears


ISTOCKPHOTO.COM / JAMES RICHEY

Polar Biol. doi:10.1007/s00300-008-0530-0 (2008)

Polar bears in the Beaufort Sea region of the Arctic are finding it increasingly difficult to find food during springtime, suggests a new study.

Seth Cherry of the University of Alberta, Canada, and colleagues located polar bears by helicopter and anesthetized them using a dart gun before taking blood samples to determine their serum urea to serum creatinine (U/C) ratios. U/C values, which are low when bears are in a physiological fasting state, were obtained for 436 individuals during April and May of 1985–1986 and 2005–2006. Of the bears sampled by Cherry's team, the numbers fasting were 9.6 per cent in 1985 and 10.5 per cent in 1986, increasing to 21.4 per cent in 2005 and 29.3 per cent in 2006. Polar bears from all sex, age and reproductive classes were more likely to be found fasting in 2005–2006 than in 1985–1986. During all years of the study, adult males involved in breeding comprised a high proportion of the bears with low U/C levels.

Satellite data over this period shows significant declines in the extent of Arctic sea ice, a change that may affect the bears' ability to hunt and catch seals during the spring feeding period.

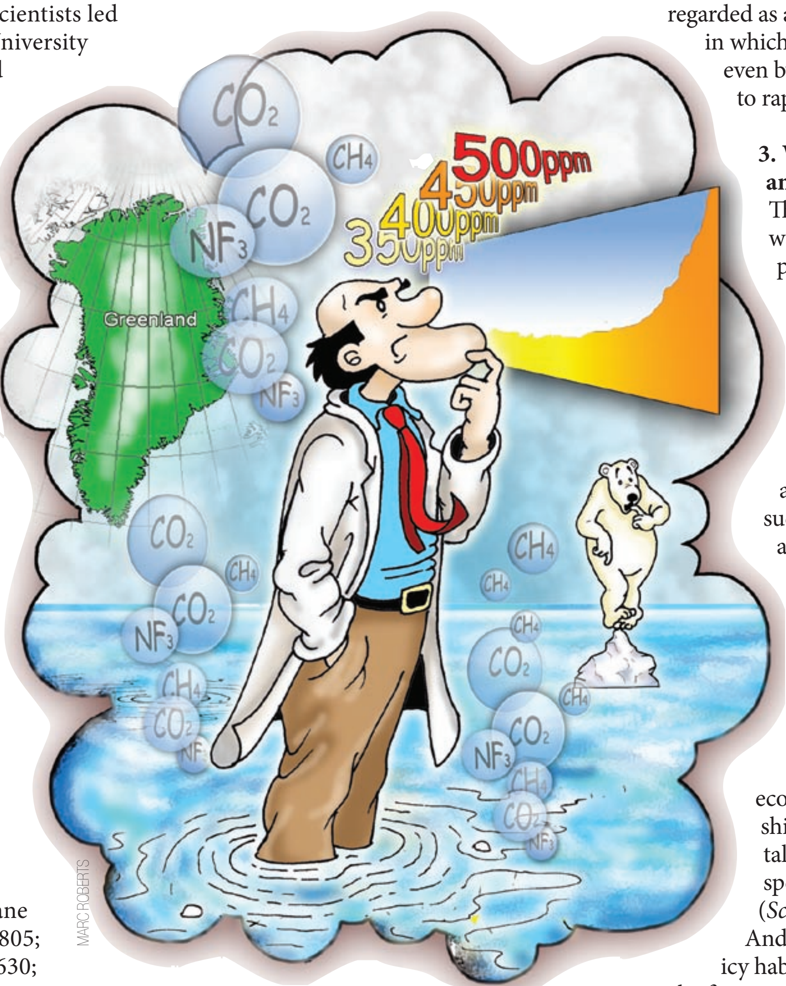
Olive Heffernan

What we've learned in 2008

Amanda Leigh Mascarelli looks at how far our understanding of climate change has come in the past twelve months.

1. Other greenhouse gases are also worrying
Scientists have long been aware of greenhouse gases other than carbon dioxide, but CO_2 has received most of the scientific and public attention owing to its prevalence in fossil fuel emissions and its long atmospheric life. However, scientific research published this year suggests that other heat-trapping gases also provide cause for concern. In July, scientists led by Michael Prather at the University of California, first proposed that nitrogen trifluoride, a gas produced in the manufacture of gadgets such as MP3 players and flat screen TVs, was likely to become a much greater contributor to climate change than previously assumed, mainly because of the growing demand for such products (*Geophys. Res. Lett.* **35,** L12810; 2008). Their hypothesis was confirmed in October when Ray Weiss at the Scripps Institution of Oceanography, California, and colleagues found that the atmospheric concentration of the gas has increased 20-fold over the past three decades (*Geophys. Res. Lett.* **35,** L20821; 2008). Also this year, several independent research groups reported a surge in emissions of methane (*Geophys. Res. Lett.* **35,** L22805; 2008 and *Nature* **456,** 628–630; 2008), a greenhouse gas twenty times more potent than CO_2. The exact source of the methane emissions remains a mystery.

2. Arctic summer sea ice is in rapid decline
Arctic sea ice saw some recovery this summer, compared with the record-breaking low set in 2007. However, the 2008 summertime minimum was still the second lowest level recorded since 1979, when the first satellite data of sea ice became available (*National Snow and Ice Data Center* 16 September 2008; http://nsidc.com/arcticseaicenews/2008/091608.html). In 2007, the Intergovernmental Panel on Climate Change (IPCC) projected that at the current level of emissions, summer sea ice could vanish completely anytime from 2040 to beyond 2100. But the extensive losses during the past two summers have led scientists to speculate that the Arctic Ocean may be ice-free in the summertime much sooner than anticipated. In October, scientists reported that the thickness of winter sea ice plummeted after the 2007 minimum, showing that the ice pack is not only shrinking but is decreasing in overall volume (*Geophys. Res. Lett.* **35**, L22502; 2008). This is worrying because thin ice is more vulnerable to melting and creates a feedback effect: as the ice melts, dark open water soaks up more of the sun's rays and further accelerates melting. Loss of Arctic summer sea ice could have not only regional, but global, effects and is widely regarded as a potential 'tipping element', in which a 'kick' to the system, driven even by natural variability, could lead to rapid, runaway warming.



3. Warming is already having an impact
The effect of human-induced warming on biological and physical systems, such as patterns of species migration and seasonal shifts, came into clear focus this year. An international team of researchers conducted a sweeping analysis of nearly 30,000 biological species and physical phenomena, such as timing of pollen release and bird nesting, and trends in ice melting. For the first time, researchers attributed pronounced worldwide changes in these systems to human-caused climate change (*Nature* **453,** 353–357; 2008). Spurred on by concerns that species and ecosystems may not survive such shifts, conservationists began to talk seriously about relocating species to help them adapt (*Science* **321,** 345–346; 2008). And threatened by the loss of its icy habitat, the polar bear became the first species to be listed as climate-threatened under the Endangered Species Act, following a protracted legal battle by environmentalists.

4. The hockey stick holds up
A follow-up to the infamous 1998 'hockey stick' curve confirmed that the past two decades are the warmest in recent

history. Climatologist Michael Mann's contentious graph has become a symbol of the fierce debates on evidence for global warming, to the extent that an independent investigation into the study was performed at the request of US Congressman Joe Barton. The 2006 report that resulted from the Barton enquiry criticized Mann and colleagues for their reliance on tree-ring data from bristlecone pines as a proxy to reconstruct Northern Hemisphere temperatures over the past 1,000 years. Although their earlier work had been largely vindicated, in September the same team revised their global surface temperature estimates for the past 2,000 years, using a greatly expanded set of proxies, including marine sediments, ice cores, coral and historical documents *(Proc. Natl Acad. Sci. USA* **105,** 13252–13257; 2008). The team reconstructed global temperatures with and without inclusion of the tree-ring records: without their inclusion, the data showed that recent warming is greater than at any point in at least the past 1,300 years; inclusion of tree-ring data extended this period to at least 1,700 years. According to the Christian Science Monitor: "It still looks a lot like the much-battered, but still rink-ready stick of 1998. Today the handle reaches further back and it's a bit more gnarly. But the blade at the business end tells the same story."

5. Sceptics are still out there

Despite a near-universal scientific consensus to the contrary, climate change sceptics continued this year to insist that global warming is a farce. Although the Republican party officially acknowledges the role of humans in climate change, Alaskan Governor Sarah Palin remained unconvinced during her campaign as Senator John McCain's vice presidential running-mate, asserting "I'm not one though who would attribute [global warming] to being manmade". The NBC late night show *Saturday Night Live* famously satirized Palin: when asked about her views on global warming, Palin's double Tina Fey responded, "I believe it's just God hugging us closer." More recently, climate bloggers have been up in arms over two articles published by the website *Politico*. One calls into question the science behind global warming and the other suggests that extreme cold-weather events coincide with appearances by former US vice president Al Gore. Little wonder that American public opinion still fluctuates over whether climate change is a serious problem (*Wired Science* 14 May 2008; http://blog.wired.com/wiredscience/2008/05/the-climate-cha.html).

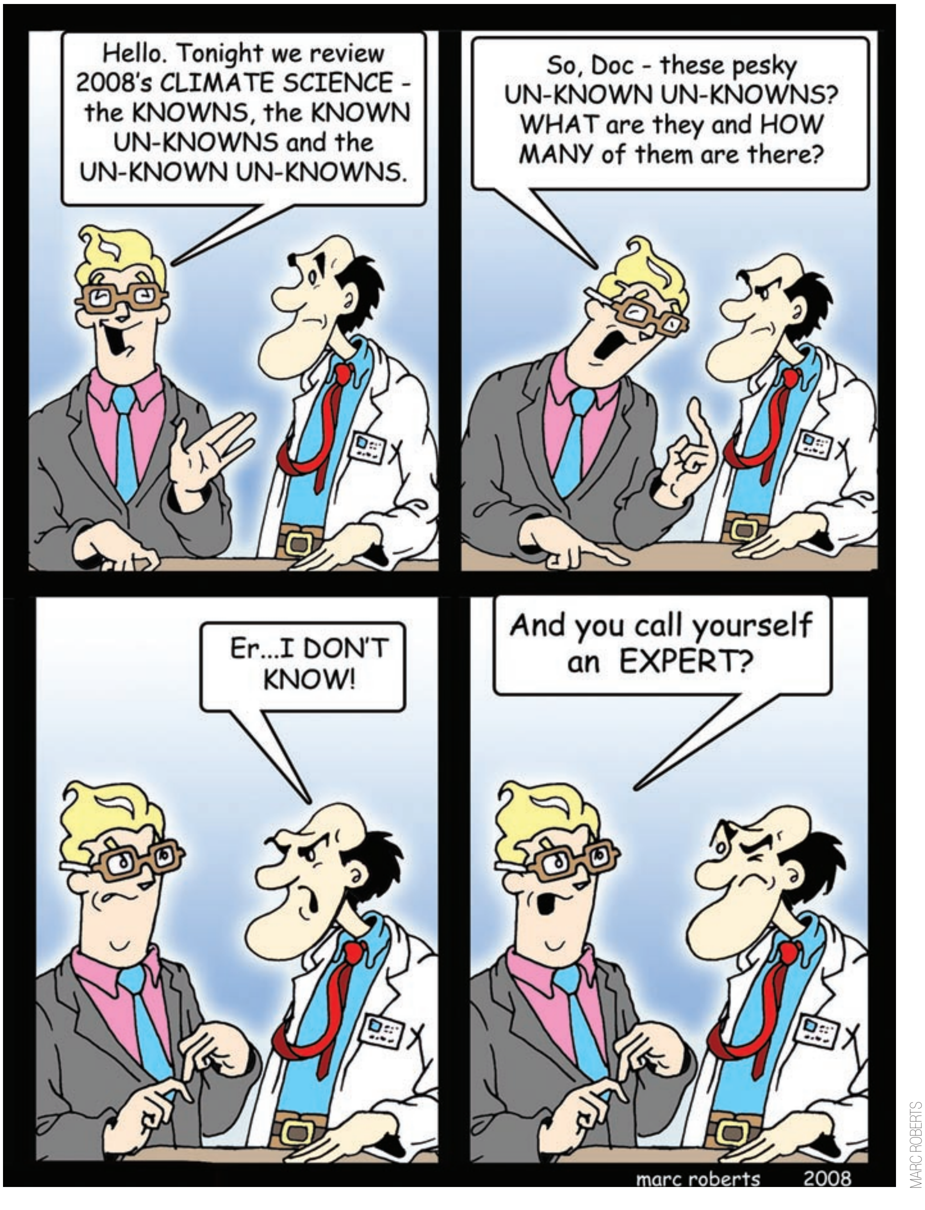
AND WHAT WE'RE STILL WORKING ON

1. How much warming and by when

Although there is wide agreement that we will see a warming trend in atmospheric and sea surface temperatures over the next century, just how climate will change in the short term is less certain. One of the first studies to address this concluded that warming may slow for a decade before rapid climate change takes off (*Nature* **453,** 84–88; 2008). Noel Keenlyside of the Leibniz Institute of Marine Sciences, Germany, and colleagues found that owing to changes in ocean circulation that occur on decadal time scales, global average surface temperatures in parts of the ocean may not increase over the period from 2005 to 2015, compared with 2000 to 2010, and that some surface waters could even cool slightly. Their findings do not imply that global warming is not happening, but instead that natural oscillations in the climate system could lead to short-term changes that temporarily eclipse human-induced warming. However, unconvinced by the temperature forecasts of Keenlyside *et al.* a group of esteemed climate scientists on the Real Climate blog staked €5,000 against the prediction that falling temperatures in some regions will cause a slight slow down in global warming. We'll have to wait until 2015 to know for sure.

2. Where to stabilize

A muddy point that perhaps only became muddier in 2008 is the concentration at which we must stabilize atmospheric greenhouse gases to avert a dangerous degree of change. Atmospheric CO_2 concentrations today hover around 385 parts per million (p.p.m.), and many



MARC ROBERTS

scientists have settled on 400 to 450 p.p.m. as the upper limit to keep warming below 2 °C above pre-industrial levels. But NASA climatologist James Hansen is one of a group of scientists now saying that more stringent limits of approximately 350 p.p.m. will be necessary to avoid "irreversible catastrophic effects" (J. Hansen *et al. Columbia University* 2008; www.columbia.edu/~jeh1/2008/TargetCO2_20080407.pdf). Others are veering in the opposite direction: in a report for the Australian government this year, economist Ross Garnaut reiterated Professor Nick Stern's 2006 recommendation to stabilize the atmospheric concentration of CO_2 at up to 550 p.p.m. (R. Garnaut, *The Garnaut Climate Change Review*; Cambridge University, 2008; www.garnautreview.org.au/index.htm). There may be remaining scientific uncertainty about just how much CO_2 is too much, to avoid disaster, but if the current state of play is anything to go by, reaching a final figure in any agreement will also be a question of what is politically achievable.

3. Where the missing carbon is going

Surprising as it sounds, scientists still do not have a clear grasp of where carbon is coming from, where it's going and in what amounts. Yet, under the Kyoto Protocol, developed nations that have ratified the agreement are to receive credits for sequestering carbon through improved land management practices and reforestation. About half of the CO_2 that wafts into the atmosphere from fossil fuel combustion is absorbed by the oceans, plants, forests and croplands, but how much of the carbon is swallowed up by the oceans versus land is still unclear (*Global Change Biol.* **14,** 2910–2922; 2008, *Nature Geosci.* **1,** 569–570; 2008 and *Eos Trans. AGU* **89,** doi:10.1029/2008EO430001; 2008). One reason for the dearth of information is that ground-based monitoring stations are few and far between, and until now, the technology hasn't been available to obtain fine-scaled, precise measurements of CO_2 in the atmosphere. But the launch next year of two carbon-detecting satellites, NASA's Orbiting Carbon Observatory and the Japanese Greenhouse Gases Observing Satellite, should soon help to fill in this knowledge gap, which is critical to establishing a reliable carbon accounting system.

4. Whether warming worsens storms

The jury is still out on whether hurricanes will increase in intensity, frequency or duration as a result of global warming. Globally, the number of major hurricanes has shot up by 75 per cent since 1970, but the role of human activity in this rise has remained contentious. This year, new evidence has caused leading experts to reassess their positions on this key issue. Weighing in on the debate early on, Kerry Emanuel of the Massachusetts Institute of Technology used a bespoke model to show that warming should reduce the frequency of hurricanes globally, although hurricane intensity may increase in some locations (*Bull. Am. Meteorol. Soc.* **89,** 347–367; 2008). Supporting these predictions was a paper in May (*Nature Geosci.* **1,** 359–364; 2008) that projected fewer Atlantic hurricanes during the twenty-first century. In September, James Elsner of Florida State University and colleagues concluded that in the Atlantic, the strongest tropical cyclones will grow even stronger in a warming world (*Nature* **455,** 92–95; 2008). One explanation for the smattering of results is that scientists do not yet have a clear understanding of the relationship between sea surface temperature and hurricane formation on local or global scales. A team of researchers led by Gabriel Vecchi of the US National Oceanic and Atmospheric Administration recently summarized the difficulties in predicting hurricane activity (*Science* **322,** 687–689; 2008). Ultimately, they argue that relative, rather than absolute, warming of regions such as the Atlantic Ocean is probably behind the recent surge in hurricane activity. And predictions show that relative warming will remain fairly constant throughout the remainder of this century. If their hypothesis is right, the worst hurricane seasons may already be behind us.

5. How fast Greenland is melting

One of the greatest wild cards in predicting how the climate system will respond to warming is the Greenland Ice Sheet. Complete melting of Greenland could raise sea level by seven metres and spell catastrophe for coastal cities and millions of inhabitants. Scientists previously assumed that this melting would happen gradually over 1,000 years or more. However, this is being re-examined in light of new evidence, including a study showing that Greenland could experience rapid melting over centuries, rather than millennia, and that sea level could rise by 1.3 metres by 2100 as a result (*Nature Geosci.* **1,** 620–624; 2008). A recent study reported in *Science* looked closely at the possibility of large sea level rise by 2100 and concluded that sea level could rise by a maximum of two metres by 2100 if all variables were accelerated and pushed to the extreme, but that sea level rise of 0.8 metres by 2100 is a more likely outcome (*Science* **321,** 1340–1343; 2008). Scientists know that the Greenland Ice Sheet is undergoing dramatic melting, but accurately capturing its status in climate models and predicting future behaviour in response to warming is difficult due to a lack of long-term observations and data. In addition, scientists don't yet have a handle on ice sheet dynamics, including how subsurface melting contributes to slipping and sliding of the ice sheet. Two studies this year shed light on how meltwater may lubricate the bottom of the ice sheet, contributing to its slippage towards the ocean (*Science* **320,** 778–781; 2008 and *Science* **320,** 781–783; 2008). But by far the most disturbing question that remains is whether Greenland has already endured enough warming to push it to the point of no return.

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Amanda Leigh Mascarelli is a freelance science writer based in Denver, Colorado.

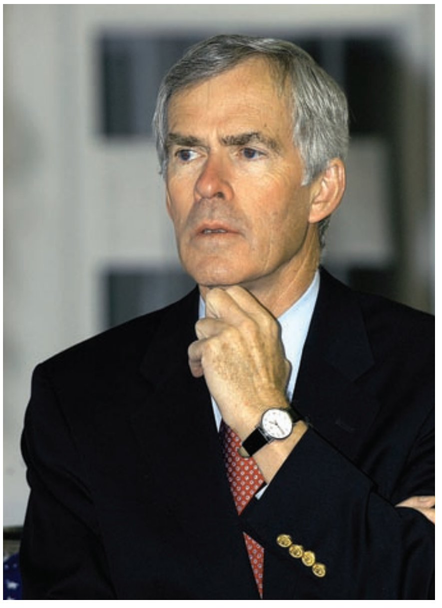
Agency for energy innovation may be funded under Obama

Proponents of a new US energy agency are hopeful it will finally take off. **Kurt Kleiner** reports.

A new research programme, designed to bypass bureaucratic red tape and bring 'transformative' energy technology to the market, could finally win approval in the United States under a new Obama administration and a Democratic Congress. Supporters have been pushing for the new agency — to be modelled on the Department of Defense Advanced Research Projects Agency (DARPA) — since the National Academy of Sciences proposed it in a 2005 report[1]. Called the Advanced Research Projects Agency-Energy (ARPA-E), it would spend as much as a billion dollars a year on energy research to create clean alternatives to fossil fuels.

Congress voted to create ARPA-E in 2007, despite the objections of the Bush administration, but has since failed to provide funding to actually implement the programme, leaving it authorized on paper only. The recent election of Barack Obama as US President, however, has brought hope that it will now finally materialize. Obama promised during his campaign to spend $150 billion over 10 years on renewable energy research, but has not committed specifically to ARPA-E. Jeff Bingaman, a Democratic senator from New Mexico and chairman of the Senate Energy and Natural Resources Committee, recently called for Congress to fund the agency[2], as did Bart Gordon, a Democratic congressman from Tennessee who chairs the Committee on Science and Technology.

"The need for the new technologies is greater than ever because of the economic conditions," says Gordon. "Innovation — especially new energy technologies — is the path to reinvigorating our economy and ensuring our competitiveness over the next 50 years." Last week's announcement that rocket scientist and Nobel laureate Steven Chu, who runs the Lawrence Berkeley National Laboratory at the University of California, will be secretary of energy as of next year has further thrilled energy transformation advocates and bodes well for ARPA-E.


PA PHOTOS

US Senator Jeff Bingaman.

The US already spends about $4 billion a year on energy research through the Department of Energy (DOE), but the hope is for ARPA-E to develop the next generation of breakthrough technologies; thereby replicating the success of the legendary DARPA. Established in 1958 in response to the Soviet launch of Sputnik, DARPA has since given birth to technologies as diverse as the Saturn rocket engine, which made the Moon landings possible, global positioning satellites, unmanned Predator airplanes and perhaps most notably, the Internet. "I think because of the nature of the energy challenge it demands some new thinking and new ways of doing things," says Stephen Forrest, Vice President for Research at the University of Michigan, a supporter of ARPA-E. "This is really to focus fast moving and agile research particularly in the area of renewable energy." ARPA-E would probably finance research into familiar areas such as advanced batteries, fuel cells, solar, wind, hydrogen and geothermal power, and biofuels. But its mandate would be to look for research where increased financial support would bring major breakthroughs that could help shift the US from fossil fuels to cleaner, renewable energy sources.

IMPORTANT DISTINCTIONS

Unlike DOE funding, which goes largely to researchers at its own national laboratories and research centres, DARPA does not manage facilities or conduct research itself. Instead, it relies on a staff of project managers who finance outside researchers for projects that last three to five years. Project managers are largely autonomous, and face few bureaucratic impediments, according to a Congressional Research Service report prepared for Congress in August. In its 2005 report the National Academy of Sciences concluded that "Introducing a small, agile, DARPA-like organization could improve DOE's pursuit of R&D much as DARPA did for the Department of Defense." A main goal of ARPA-E will be to forge partnerships among government, businesses and academic researchers, Forrest says. It would probably concentrate on long- and medium-term research.

> "People who promote ARPA-E are operating under many misapprehensions. They think the Department of Energy doesn't know how to do R&D."
> Joseph Romm

"The main genesis for it is the desire to really coordinate research activities," says Daniel Kammen, Director of the Renewable and Appropriate Energy Laboratory at Berkeley. ARPA-E would pursue research with an eye to bringing important new technologies to market. "The real issue is the integration. It's not so much that the science itself would be inherently different," he says. How well it fulfills that mission will depend largely on the people in place and their vision. Ideally, project managers will be made up of active research scientists with good ideas about what areas of research to fund, Forrest says.

> "Because of the nature of the energy challenge, it demands some new thinking and new ways of doing things."
> Stephen Forrest

But critics of the proposal say it risks either replicating existing DOE research, or siphoning funds from existing programmes. "The question is, what role is it fulfilling that isn't happening now?" asks Joseph Romm, a senior fellow at Washington think-tank, the Center for American Progress, and former acting assistant secretary at the DOE's Office of Energy Efficiency and Renewable Energy. "The Department of Energy has a major research and development programme that has been phenomenally successful. People who promote ARPA-E are operating under many misapprehensions. They think the

PA PHOTOS

An unmanned Predator airplane, one of the many breakthrough inventions of DARPA.

Department of Energy doesn't know how to do R&D," he says.

Although Romm admires DARPA, he says that an energy research programme will probably not be able to duplicate it. "There is no analogy between energy research and Department of Defense research. If you have begun a project that the military says it wants, you will be successful. There's one customer, and the price is no object." On the other hand, Congress tends to meddle in energy research, earmarking funding for favourite programmes, increasing overall funding some years and decreasing it in others. "Somehow I doubt Congress is going to authorize a programme that it's not going to finagle with," Romm says. Where the money will come from is another question. A number of different bills pending in Congress contain different suggestions. The money could come from general revenues, from funds raised through carbon taxes or from oil and gas lease revenues.

It's not clear when ARPA-E's future will be decided. It could receive funding from Congress as soon as February, as part of the final appropriations for fiscal year 2009. Otherwise, supporters may have to wait for an answer until President Obama makes his first budget proposal for 2010, in May.

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Kurt Kleiner is a freelance science writer.

Here comes the flood

JANOS BOGARDI AND KOKO WARNER

Policymakers must start to view mass migration as a form of adaptation so that the global response to climate-induced migration is one of facilitation rather than neglect.

Two leviathans are about to collide on the world stage of science and politics — climate change and migration[1]. Their combination brings us to a tipping point that could spawn a phenomenon of a scale and scope not experienced in human history[2]. Beyond reducing the greenhouse gases that drive global warming, we are now faced with the task of finding ways to deal with the impact of climate change. Next in line, perhaps even ahead of mitigation, adaptation is the new game in town.

Governments of some 192 nations are currently meeting in Poznan, Poland, for the latest round of UN climate talks. This marks an important step along the road to the Copenhagen summit in 2009, when world leaders will decide on the architecture of a climate deal to replace the Kyoto Protocol when it expires in 2012. Timing is therefore crucial — in the coming months climate negotiators must define a plan that will address the increasing vulnerability, particularly of developing countries, to rapidly changing environments that help fuel migration. If done in an orderly manner, migration may be seen as an adaptation measure, but the same term also covers precipitous flight for survival. The global response to this situation could tip towards the negative or positive. Here we call on countries, particularly climate negotiators, to address this issue with swift decision making and to adopt a balanced approach to climate-induced migration.

FLIGHT FOR SURVIVAL

Already, some countries cannot afford to wait for a new climate deal. Nations such as the Maldives now anticipate the loss of their sovereign territory. In November their President-elect, Mohammed Nasheed, announced the islanders' wish to buy a new homeland as sea level rise threatens to drown the archipelago, most of which lies only 1.5 metres above the surface of the Indian Ocean. Nasheed told the media, "I don't want Maldivians to end up as environmental refugees in some camp … if the islands are sinking we must find high land some place close by. We should do that before we sink[3]."

If done in an orderly manner, migration may be seen as an adaptation measure, but the same term also covers precipitous flight for survival.

As the longer-term effects of sea level rise and desertification become increasingly apparent, and extreme events, such as flooding and droughts, become more frequent and severe, liveable surface area will become restricted. For regions that experience a systematic economic collapse, environmentally induced migration could affect millions and come at a time when points of 'no return' have been crossed for critical ecosystem services[4]. Owing to migrant network connections, environmental degradation may perpetuate existing patterns and drive the movement of people towards traditional destinations. Such migration flows will increasingly originate from resource-stressed environments — areas where large-scale humanitarian assistance or peacekeeping is already required.

Consider, as an example, that up to 120,000 migrants from sub-Saharan Africa enter northern Africa every year. Some seek a better life there, while tens of thousands attempt to cross the Mediterranean. Their destination is Europe. Since 2006, experts have witnessed a sharp increase in attempted crossings. Between January and September 2006, around 24,000 migrants arrived on the Canary Islands, a considerable increase compared with 4,772 in 2005 and 9,900 in 2002 for the same period. The first seven months of 2006 saw 10,400 migrants detained on the

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Inhabitants of the Maldives plan to buy a new homeland, as sea level rise threatens to drown the archipelago.

Italian island of Lampedusa south of Sicily, compared with 6,900 over the same period in 2005 [ref. 5].

Drought, desertification and other forms of water scarcity are estimated to affect as much as one-third of the world's population today. As this worsens, it will increase the flow of people migrating away from areas such as sub-Saharan Africa in order to secure their livelihoods (Fig. 1). The scale of such flows, both internal and cross-border, is expected to rise, with unprecedented effects. The most widely cited estimate of 200 million additional migrants by 2050 suggests that environmentally induced displacements could involve almost three per cent of the present world population in just four decades from now[6]. These estimates, including the underlying methods, are subject to scientific debate[7]. And the social and economic costs of this uprooting, accounting for both losses and responses, so far remain unknown. Good science is essential, but the need to clarify academic controversies is not an excuse to leave creeping processes unaddressed.

IN THE BALANCE

The post-2012 climate agreement will lock the international community into an agreement to address mitigation and adaptation for the coming 10 to 15 years. It is therefore vital that migration be addressed within that process and a platform for dialogue and exchange be created so that no more precious time is lost. Other looming problems, including the financial, food and energy crises may tempt countries to take a defensive stance and ignore the growing plight of people on the move. Indeed, the current economic situation could even be an excuse to ignore the consequences of worsening climatic conditions. We now find ourselves in a defining moment where the global response to this situation could evolve towards the negative or positive. Short-sightedness could prove fatal.

If the balance tips towards the positive, we may see compromise and rapid action. Mass-scale resettlement programmes are now in the realm of the politically thinkable. Islands of the Pacific, countries located in deltas and flood-prone coastal areas are already pursuing resettlement programmes as a matter of national policy. Government responses vary from offering 'mobility incentives' to mandatory resettlement programmes, with mixed results. Relocation moves people out of harm's way. But resettlement is expensive, and exposes displaced people to loss of livelihood, debt and disintegration of communities, without addressing the environmental stressor itself. The Australian and New Zealand governments are exploring the sovereign resettlement of their Pacific neighbours. Some countries such as the Maldives, Tuvalu, Kiribati, Mozambique, Egypt and others are already planning for the relocation and resettlement of affected populations.

In other regions, such as the US, political shifts open the door for a considerable rethink on migration policies. In the EU, political interest in acknowledging environmentally induced migration is also growing, partly owing to Europe's proximity to Africa and migration pressures topping the political agenda. The reformulation of migration policies brings opportunities to decriminalize migration, and to win time as some countries try to find solutions to their shrinking land area.

If, on the other hand, the balance tips towards the negative, then delayed action practically guarantees a humanitarian crisis. Policymakers could find migration too complicated an issue to tackle, and may turn their backs on efforts to understand its interaction with climate change. Such a scenario would put culture, social structure, peace, resources and political stability in grave danger. Domestic, international and other crises could promote defensive thinking and frame migration as a threat. The result would be to close any window of opportunity to help environmentally devastated areas before a humanitarian crisis becomes widespread. Failure of climate negotiators to decide on an acceptable successor to the Kyoto Protocol could exacerbate the drivers of climate change, while leaving those most affected empty-handed and more likely than ever to migrate. Conversely, the success of international climate negotiations could not only steer policy in the right direction, it could have the extra benefit of giving hope to those affected.

A WAY FORWARD

Now is the time to decide which way the scale will tip. With an agreement on the post-Kyoto Protocol due at the end of next year in Copenhagen, negotiators have shown a willingness to consider proposals about how to address environmental change and migration. We urge parties involved in the climate negotiations leading up to the UN conference to adopt a 'five-pronged approach'. Conceived by the UN University Institute for Environment and Human Security (UNU-EHS), this framework[8] acknowledges the need for

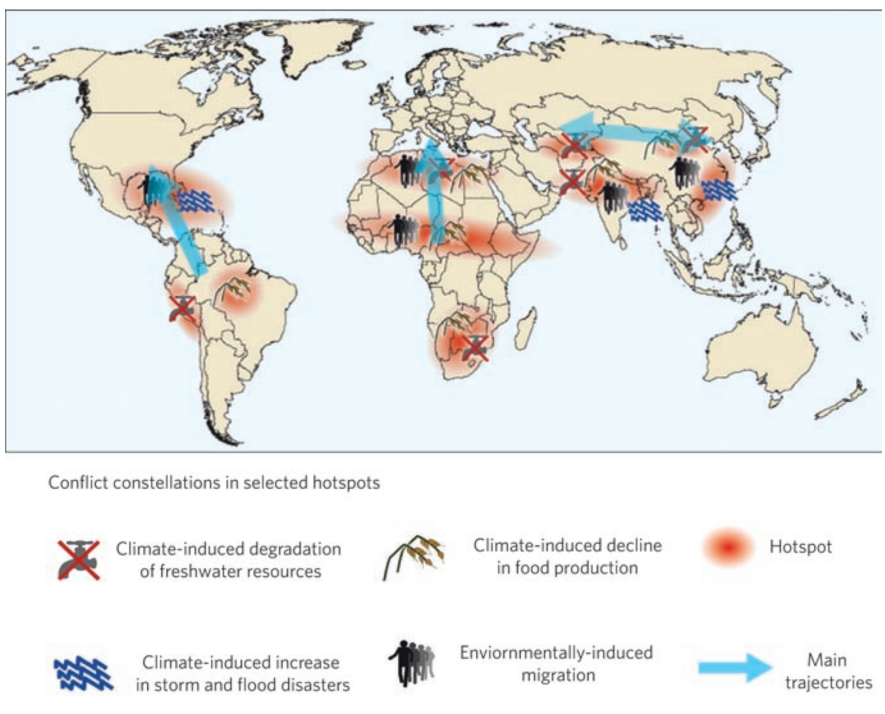

Figure 1 Migration, environment and conflict. Areas where drought, desertification, and other forms of water scarcity are expected to worsen, and could contribute to people migrating away from these areas to secure their livelihoods. Main projected trajectories are added where climate change-related migration can be expected in the future. Figure source: German Advisory Council on Global Change WBGU. *Climate Change as a Security Risk* (2008) reprinted with permission, modifications by authors.

further research and calls for simultaneous and concerted efforts in five areas including science, public awareness, legislation, strengthening institutions, and humanitarian response.

First is the need to build a strong scientific base, to make real progress in understanding the interactions between climate change and migration. This could be accelerated if the scientific community fostered rigorous, sustained quantitative research. The EU spearheaded this task in 2007, but additional work must be initiated immediately. Second, the concept of environmental migration and environmentally displaced persons needs to be included in the agreed outcome of the Copenhagen summit next year, as well as in continuing work by the UN Convention to Combat Desertification and the Intergovernmental Panel on Climate Change (IPCC). Awareness and inclusion in international protocols is a vital early step to improving frameworks and legislation that manage migration issues. However, adding a new category to the Geneva Convention could weaken the case of categories of refugees already covered by it, and hence this is not an option. Individuals who are clearly displaced by environmental degradation (even if mixed with other socio-economic factors, as will often be the case) should be protected adequately by an international mechanism that would afford them certain rights.

Furthermore, the continuing climate negotiations should call for an international mechanism to recognize this category of individuals. This would empower relevant entities in the UN system, and other main humanitarian assistance organizations, to provide aid to environmentally displaced people, particularly when considering the displacement of entire communities. In addition, climate negotiators should discuss institutional cooperation, possibly through regional centres, to help ensure safe, non-criminal and orderly migration relations pertaining to climate change and adaptation. As an example of such collaboration, the International Organization for Migration (IOM), the United Nations Environment Program (UNEP), United Nations University and the Munich Re Foundation (MRF) have decided to merge their activities to form the Climate Change, Environment and Migration Alliance (CCEMA) as a multi-stakeholder global partnership. The alliance helps to mainstream environmental and climate change considerations into the migration management policies and practice, and to bring migration issues into the world's environmental and climate change as well as development discourse. Finally, further cooperative efforts are needed to improve monitoring and assistance of migration, including an increased ability to confront criminal activities, such as smuggling and trafficking. However such efforts will require appropriate resources.

With increasing numbers of the world's population living in areas exposed to the negative consequences of climate change, we need urgent action to identify adaptation pathways that prevent or at least reduce environmental migration flows. A rapid and collaborative effort is needed to discuss options, including resettlement, and to further understand the implications of climate change-related migration for affected countries and regions. Fundamentally this requires dialogue about things we know already, as well as vigorous imagination, to find alternatives that will keep this planet a home for all of us, rather than for just the fortunate few.

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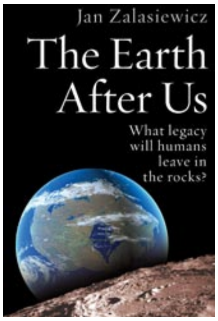
Looking back from the future



THE EARTH AFTER US: WHAT LEGACY WILL HUMANS LEAVE IN THE ROCKS?

by Jan Zalasiewicz

Oxford University Press: 2008. 272 pp. $34.95/£14.99

If future explorers came across evidence of human civilization 100 million years from now, what impression would they have of our existence?

The late, great Douglas Adams once said: "We don't have to save the world. What we have to be concerned about is whether or not the world we live in will be capable of sustaining us in it."

There's no doubt we face formidable challenges. Rising extinction rates, global pollution and a dramatically changing climate are just some of the many issues that confront us today. Collectively, we tend to focus on the fall-out from these problems in the immediate future, typically over the next few decades. At one level, this isn't surprising. After all, it's a timescale that most of us can relate to. It neatly captures our own lives and any hypothetical grandchildren we may have. But from the point of view of a planet that is 4.6 billion years old, we are relative newcomers. With a track record that spans just the last couple of hundred thousand years, humanity has missed most of our planet's long and colourful adolescence. It is rather depressing to consider just how much longer we might have as a species, but if you take an improbably distant future, a different and far more interesting question presents itself: what sort of evidence for our existence might be left in the geological record?

It is in this context that Jan Zalasiewicz's *The Earth After Us* provides a wonderfully thought-provoking and fascinating look at the impression we're leaving on our planet. Zalasiewicz, a geologist by profession, does a fantastic job of setting out what evidence we'll leave behind in the rocks, taking a refreshing look from the perspective of millions of years into the future when there are no humans. The Prologue immediately grabs the reader — in the future Zalasiewicz imagines, academia is inhabited by a species of extra-terrestrials who argue over the controversial idea that we once existed. But then comes a discovery that changes everything: an expeditionary force of explorers searching a latter-day Grand Canyon find clear evidence of humans in the geological sequence. Precisely who or what is doing the exploring is never explained, but that is not the issue. The key point is what they discover.

In spite of all our grand achievements, the wheel and New York City, among others, the explorers find just a thin layer of decayed debris exposed in a cliff face — clinching evidence of our presence on a planet millions of years before. Covering the full gambit of natural processes that shape our planet, Zalasiewicz explores what the past has left in the geological record and what this means for the present and future. But this is not a formulaic look at the Earth's processes and history. Because of the massive timescale, all manner of geological mechanisms come into force and are neatly put into a broad view of what has yet to come: the pinnacles of our civilization are washed and ground away so that the vestiges of our monuments make up an urban stratum in the geological record of the future. The environmental destruction we're wreaking is found sandwiched between evidence of natural change: ancient mudstones preserve abundant grass pollen, testifying to the advance of modern agriculture and what Zalasiewicz describes as our 'MacDonaldization of life'. Coral reef destruction, ocean acidification and sea level rise leave their mark in other ways, all clearly anomalous to what has gone before. Through the eyes of explorers millions of years into the future — albeit visitors from outer space — the damage we're doing is seen to be massive. As their discoveries increase, the neo-Indiana Joneses exploring our planet become increasingly exasperated over how such a 'great' civilization could behave in this way.

It is sobering to consider what sort of legacy we're bequeathing our planet and in this regard the *The Earth After Us* is a thoroughly inspirational book. At all levels, it provides a fantastic introduction to the world about us taken from a highly original angle. But regardless of who delves into this book, be it the general public or a student of earth science, one important message comes through loud and clear: we're increasingly leaving a mark on the Earth. With all our knowledge, can we avert disaster and reduce the effect we're having? By writing such an accessible book, Zalasiewicz provides a great call to arms. It's not too late to do something about the dreadful mistakes we're making. We can listen to the past, change our ways and make our footprint on the planet considerably smaller. To quote Douglas Adams: "We live and learn. At any rate, we live."

Let's hope we can learn.

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