Global Change

International Geosphere-Biosphere Programme

Issue 74 ▮ Winter 2009

PLANETARY BOUNDARIES

Nine identified

Three crossed

Global CO_2 budget
Variations and trends

A vision for 2050
The future could be bright

Cimate-change index
A new tool for the public and policymakers

GLOBAL IGBP CHANGE
International Geosphere-Biosphere Programme

www.igbp.net
Earth-system science for a sustainable planet

ICSU
International Council for Science

Contents

Global Change primarily publishes articles reporting science from within the extensive IGBP network.

Published by:
IGBP Secretariat, Box 50005, SE-104 05, Stockholm, SWEDEN

To subscribe, unsubscribe or change your details email: charlottew@igbp.kva.se

Printed by Bergs Grafiska, Sweden

ISSN 0284-5865

Circulation: 10, 000 copies

If you have an idea for a feature article or news, email Science Editor Ninad Bondre ninad.bondre@igbp.kva.se

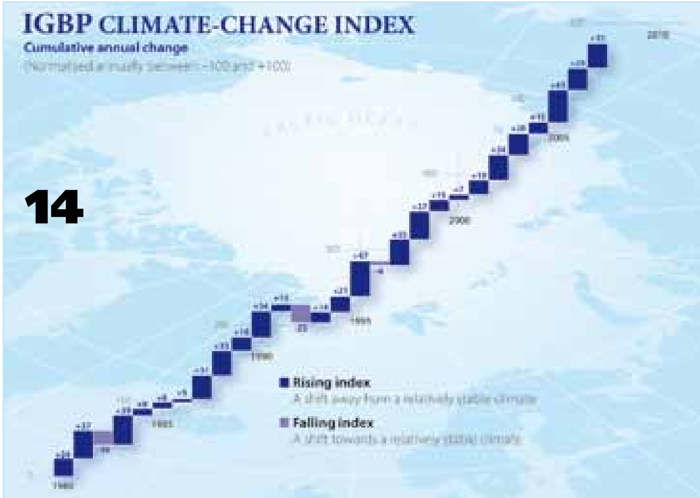
Editor: Ninad Bondre
ninad.bondre@igbp.kva.se

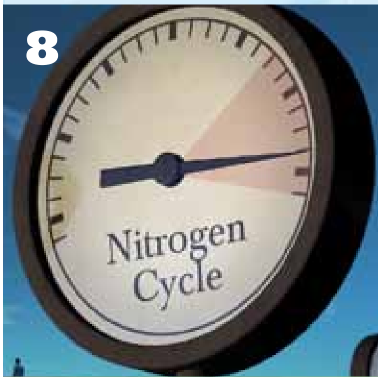
Director of Communications: Owen Gaffney
owen.gaffney@igbp-kva.se

Graphic designer: Hilarie Cutler
hilarie@igbp.kva.se

Cover image

Maintaining the long-term environmental stability of the Holocene, some experts suggest, will require respecting nine interlinked planetary boundaries that define a "safe operating space" for humanity. As the dials on the image depict, we have already overstepped three of the boundaries.





Welcome to Global Change, the new magazine from the International Geosphere-Biosphere Programme. Global Change is based on our old newsletter, which has had a long and successful history. With the new magazine, we want to broaden our appeal and reach a wider audience. It will be distributed to researchers, policymakers, funders, journalists, pressure groups and others.

This first issue is timed to coincide with the Copenhagen climate talks: many of the articles focus on recent carbon-cycle research. Of course, IGBP research goes much wider than climate change, and this will be reported in coming issues. We sincerely hope that you enjoy our magazine, and we look forward to your feedback.

Owen Gaffney
Director of Communications
owen.gaffney@igbp.kva.se

Editorial

Sybil Seitzinger, Executive Director, IGBP

ALL attention is on Copenhagen. The basis of the talks are, of course, the Intergovernmental Panel on Climate Change (IPCC) assessments and the UN's Subsidiary Body for Scientific and Technological Advice. We are asked to supply our latest research findings to both processes.

IPCC and IGBP began just over 20 years ago. Since then, climate has moved close to the top of the international political agenda and IPCC has adapted to meet the needs of governments. Indeed, IPCC is now seen as a gold standard for evidence-based policy.

The Swedish researcher, Bert Bolin, a key architect of both IPCC and IGBP, set up programmes like IGBP and the World Climate Research Programme to coordinate research internationally, and IPCC to assess it. But, IGBP was established in recognition that climate change is part of a larger challenge – global environmental change. In the last 20 years, IGBP scientists have demonstrated that humans are the main driver of global environmental change.

Is there an adequate system, like IPCC, to assess the state of knowledge of all of the planet's key natural cycles, how they are linked and how society is affecting them? Key areas in need of synthesis include the global nitrogen cycle, megacities and the coastal zone, environmental change and the needs of least developed nations, land cover and climate, aerosols and others.

IGBP's new integration, synthesis and exploration initiative (page 5), initially in ten policy-relevant areas, aims to bring together many disciplines in a truly integrated way to reduce uncertainty in the areas highlighted above. This, we hope, will contribute to a baseline for international research and policy in the coming decade.

> "Is there an adequate system to assess the state of knowledge of all key natural cycles?

GLOBAL NITROGEN ASSESSMENT NEEDED URGENTLY

HUMANITY'S colossal effect on the global carbon cycle grabs all the headlines. In many ways, our effect on the global nitrogen cycle is as big if not bigger. Now scientists say nitrogen management on a global scale is essential if we are serious about curbing climate change. This is the message from the International Nitrogen Initiative's (INI) side event at COP-15 in December.

Event co-organiser Professor Jan Willem Erisman says, "Nitrogen has effects other than climate: biodiversity loss, human health, ecosystem eutrophication and water pollution for example."

"But our understanding of the nitrogen cycle in relation to climate is poor. We are not even sure if nitrogen fertilisation leads to long-term carbon sequestration in forests," says Erisman, who is based at the Netherland's Energy Research Centre.

During the last few decades, the global increase in reactive nitrogen from human sources – largely fertiliser manufacture – has far outstripped natural production, on land at least. Since the 1960s, the rate of increase has accelerated sharply and since the 1980s the anthropogenic production exceeded natural production.


Humans have radically altered the global nitrogen cycle.
Credit: Istockphoto

All predictions are that changing diets towards more meat and food production particularly in developing countries will lead to more reactive nitrogen in circulation. But the nitrogen cycle is yet to be adequately brought into climate models.

The INI side event, sponsored by IGBP, the US State Department, the UK's Department for Environment, Food and Rural Affairs, the Dutch Ministry of the Environment, Housing and Spatial Planning and others, highlights the urgent need for a global nitrogen assessment.

INI is co-sponsored by IGBP.
www.initrogen.org

Between ice ages

THE OSCILLATION between ice ages and interglacials, the relatively warm intervals of time separating ice ages, has been a persistent feature of Earth's climate since about three million years ago.

Ice core records dating back 800,000 years show how interglacials differed widely in terms of their duration as well as climate. Given that interglacials are broadly governed by predictable cyclical changes in astronomical variables such as the tilt of Earth's rotational axis, a mystery remains as to the cause of this variability.

Researchers led by Chronis Tzedakis of the University of Leeds, UK surveyed recent progress in understanding interglacials. The group, part of IGBP's Past Global Changes project, compiled existing palaeoclimate data – such as ice volume inferred from the oxygen isotopic composition recorded by an ice core from Antarctica – to record the characteristics of interglacials.

"The occurrence of interglacials with differing characteristics is an intriguing aspect of the ice ages that raises fundamental questions about the Earth's climate", say the researchers.

What might have led to the interglacial variability? Initial findings seem to implicate changes in parameters such as the atmospheric concentrations of carbon dioxide. For example, interglacials prior to about 400,000 years ago, which were generally cooler as compared to those occurring later, were characterised by lower atmospheric carbon dioxide levels.

The maximum sea level during the penultimate interglacial was several metres higher than that today, and has been linked to melting of the Greenland and Antarctic ice sheets. This scenario is rather similar to that predicted to occur during the coming centuries, as atmospheric CO_2 concentrations peak. So, a better handle on the controls on past interglacials may hold the key to predicting how exactly the most recent interglacial that we are living in will respond to the impact of humans.

Tzedakis P C, Raynaud D, McManus J F, Berger A, Brovkin V, Kiefer T (2009) *Nature Geoscience*, 2:751-755.

On the move

IGBP SECRETARIAT

NINAD BONDRE joined IGBP as science editor in October. Until recently, Ninad was based in London as an associate editor of *Nature Geoscience.* He replaces Suzanne Nash, who was IGBP's interim information officer.

FROM 1 JANUARY 2010

IGBP Scientific Committee members

Incoming: Ray Bradley and Jean Palutikof
Outgoing: Mark Stafford Smith and Steven Running

IGBP project's Scientific Steering Committee chairs

Incoming: IGAC co-chair Paul Monks
Outgoing: Kathy Law

Incoming: ILEAPS co-chair Markku Kulmala
Outgoing: Meinrat Andreae

Incoming: IMBER chair Eileen Hoffman
Outgoing: Julie Hall

Planetary conference to be announced

A CALL to host a major planetary conference in 2012 focusing on solutions led to proposals from six countries.

The conference, entitled Planet Under Pressure: new knowledge, new solutions, hopes to attract 2500 world-leading global-change experts. It will be a key gathering of the global-change research community in the aftermath of the Copenhagen climate negotiations.

The initiative, led by IGBP, will be co-sponsored by other major international programmes. The successful host nation will be announced shortly.

Ocean acidification summary published

SCIENTISTS are calling for a global observations network to monitor ocean acidification. This is one of the key recommendations from a summary for policymakers on ocean acidification based on the outcomes of the Monaco symposium on the Oceans in a High CO_2 World.

Nine thousand copies of the English language version of the summary have been distributed to 74 nations. Demand has exceeded expectations and the summary has already been reprinted. The summary will now be translated into French and Spanish, other languages are also being planned.

The publication was written and produced by the co-sponsors of the symposium, the Scientific Commission on Oceanic Research, IGBP, the International Oceanographic Commission and the International Atomic Energy Agency. The conference also produced another publication, a short article in the journal *Oceanography* by James C. Orr and colleagues, which summarises key scientific results and the outcome of the discussions. The authors emphasise that human activities have increased the acidity of oceans, and that its ill effects on life in the oceans are likely to be felt within the coming decades. The third symposium is planned for 2012. For copies of the summary email: comms@igbp.kva.se

www.ocean-acidification.net

A call for increased south-south collaboration

A MUCH stronger network of researchers in the southern hemisphere would be “invaluable” to the Intergovernmental Panel in Climate Change, according to a workshop on climate impacts, adaptation and vulnerability in the developing world.

The workshop, convened by IGBP chair Carlos Nobre, was sponsored by IPCC and IGBP. It brought over 80 researchers, predominantly from developing countries, to São Paulo, Brazil to outline effective ways to translate research into action.

Among the principles identified at the workshop is to encourage the greater “south-south” collaboration between Africa, South America and south Asia. IPCC working-group two co-chair Chris Field said, “South-south networks are invaluable to IPCC.”

IPCC wants to encourage greater participation from authors from developing countries. Each country has an IPCC focal point that nominates experts from his or her country, but nominations are not received from all countries.

The workshop called for ways to improve the publication success rate of developing-country researchers in international journals. Two possible reasons for poor success rates are lack of confidence and the language barrier: English is rarely an author’s first language. Richard Klein from the Stockholm Environment Institute discussed his plan to develop week-long writing workshops in developing countries to overcome these barriers.

The next workshop will be held in Australia in 2010.

TEN AREAS IDENTIFIED FOR MAJOR INTERNATIONAL SYNTHESIS

Coastal megacities under the microscope.

Credit: Istockphoto

A GLOBAL nitrogen assessment, coastal megacites and geoengineering are three of ten areas in the pipeline for a major international integration, synthesis and exploration exercise led by IGBP.

The initiative, which will contribute to a baseline for international research and policy in the next decade, will bring together economists, ecologists, oceanographers, atmospheric physicists and many other disciplines to synthesise current knowledge, identify gaps and reduce uncertainties.

IGBP’s scientific committee has developed the first ten integration topics with input from IPCC, the World Climate Research Programme, the International Human Dimensions Programme on Global Environmental Change, DIVERSITAS and others.

The full list under consideration is: geoengineering; the role of changing nutrient loads in coastal zones and the open ocean in an increased CO_2 world; a global nitrogen assessment and future outlook; Earth-system resilience and prediction; Earth-system impacts from changes in the cryosphere; megacities and coastal zones; global environmental change and sustainable development: the needs of least developed countries; the role of land cover and land use in modulating climate; aerosols; and finally, supporting adaptation responses to climate change (this final topic remains provisional at this stage).

All nine IGBP core projects and four joint projects will contribute to the process. Products will include reports, review papers, briefings, summaries for policymakers and online resources. **Consultation opens 1 January 2010. www.igbp.net**

Human impacts on ecosystems

HUMAN SOCIETIES alter the productivity of natural ecosystems in myriad ways, be it by clearing forests to grow crops or by expanding grasslands to provide fodder for livestock. In a series of articles in press with the journal *Ecological Economics*, scientists associated with IGBP's Global Land Project elucidate the complex linkages between social and ecological systems.

More efficient agricultural practices can limit the human impact on ecosystems in spite of increasing populations. But as discussed in Annabella Musel's study of the human modification of ecosystems in the United Kingdom over the past two centuries, such practices tend to rely on extensive inputs of fossil fuels and fertilisers. This suggests that the burden of maintaining relatively stable ecosystems may be borne by other components of the Earth system.

Karl-Heinz Erb and colleagues analyse the ecological impacts of the global trade in biomass products. They elaborate on how ecological effects of consumption in one part of the world are often felt far away. This is because nations with low population densities – which include some of the most industrial nations such as the United States – tend to satisfy the biomass needs of densely populated countries. This finding is "counterintuitive in light of results indicating that industrialised countries increasingly rely on raw materials from developing nations", say the researchers. The flow of carbon associated with such trade in biomass is significant compared to major global carbon flows, for example, the amount of carbon released by industrial processes.

Future work of this kind is expected to help evaluate the ecological impacts and sustainability of socio- economic policies such as the reliance on biofuels.

Ecological Economics 69 (2): 250-334.

Tackle climate and air quality simultaneously, say researchers


Credit: Morguefile

THE BENEFITS of simultaneously tackling air quality and climate change in megacities are too great to ignore, say US and Chinese researchers working on IGBP's International Global Atmospheric Chemistry project.

David Parrish from the National Oceanic and Atmospheric Administration and Tong Zhu from Peking University argue in *Science* that some of the first megacities like Los Angeles could teach other megacities how to reduce pollution.

Over half of the world's population lives in cities. Nineteen cities have populations greater than ten million making them megacities. By 2025, eight more cities will likely join their ranks.

This concentration of people has potential benefits – more energy efficient buildings and transport systems, for example. But population density is linked closely to poor health, particularly respiratory and cardiovascular problems due to air pollution.

City traffic is responsible for high concentrations of surface-level ozone and particulates – small particles. Both are lung irritants and affect climate. Control strategies in Los Angeles led to lower ozone levels, but it took three decades. Ozone peaked later in Mexico City and likely never reached LA levels, before declining rapidly. Recently, Beijing authorities have aggressively clamped down on emissions from cars and trucks, even banning trucks from the city during the day to improve poor air quality.

Parrish and Zhu say that evidence from theses cities shows it is "efficient and ultimately cost effective for megacities to introduce vehicle emissions controls" as part of the growth of cities, long before pollution reaches harmful levels. The bottom line is, paying to avoid the problem is cheaper than solving it.

Zhu, IGAC's co-chair, is leading an effort to generate an "IGAC Assessment on Impacts of Megacities on Air Quality and Climate". IGBP is producing a synthesis of research on megacities and coastal zones (see page 5) and has a fast-track initiative on air-sea interactions around megacities. Both initiatives will involve IGAC researchers.

IGBP DIARY

2009

December

7-19. COP-15 side event. IGBP co-sponsors a side event on changes to the nitrogen cycle hosted by the US State Department. Copenhagen, Denmark.

7-13. Deltas: vulnerability and coastal management conference, LOICZ. Chennai, India.

2010

February

10-12. IGBP's International Project Office meeting. Stockholm, Sweden.

March

16-17. Adaptation to climate change in the Maghreb. IGBP National Committee of Morocco. Casablanca.

16-19. IGBP Scientific Committee meeting plus one-day science symposium. Grenoble, France.

May

10-13. AIMES Earth-System Science: Climate, Global Change and People open science conference. Edinburgh, UK.

June

5-8. PAGES regional workshop and scientific steering committee meeting, Nagoya, Japan.

July

11-16. Eleventh IGAC conference (with CACGP). Halifax, Canada.

September

13-17. LOICZ congress on risk and management of current and future storm surges. Hamburg, Germany.

13-15. PAGES global monsoon symposium. Shanghai, China.

October

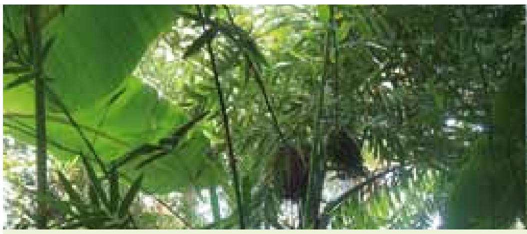
17-19. Global Land Project's first open science conference. Phoenix, Arizona, US.

Black carbon assessment underway

AN ASSESSMENT report on the role of black carbon in climate is being led by IGBP's International Global Atmospheric Chemistry project along with the World Climate Research Programme's SPARC project (Stratospheric Processes and their Role in Climate).

Black carbon – soot – has a warming effect on the planet. The dark-coloured small particles, from vehicle emissions and industry, absorb heat. It is thought that black carbon on Arctic snow has contributed to a larger than expected warming in the region.

The assessment, part of the Atmospheric Chemistry and Climate Initiative, will have key players in the US, Europe, China and India. The report could be ready by summer 2010.



Credit: Morguefile

Amazon destined to become savannah?

THE AMAZON forest is in danger of turning into a grassland if deforestation and global warming continue unmitigated, suggests a review of the anthropogenic impact on this important ecosystem. The forest acts as a vast reserve of carbon, and thereby plays a potentially crucial role in regulating local and regional climate.

The review, conducted by IGBP chair Carlos Nobre and Laura de Simone Borma from the National Institute for Space Research, São Paulo, Brazil, sought to evaluate the capacity of the Amazon forest to defend itself from the twin threats of deforestation and a warming climate. The results suggest that a loss of about 40% of the forest area and regional warming to the tune of 3-4°C could push the forest beyond a point of no return – that is, to becoming an ecosystem dominated by grasses rather than trees. The forest has already shrunk by 15% during the past four decades, while temperature has risen by about a quarter of a degree per decade. Current estimates suggest that the forest will lose a further 25% of its original area by the year 2050. "Regional climate changes induced by the large-scale deforestation itself could prevent the re-establishment of the forest", say the researchers, highlighting the positive feedback between changes in climate and modifications to forest ecosystems.

Increasing levels of atmospheric carbon dioxide and expected higher rainfall in the region could lead to more growth and increase the forest's longevity, but gauging their precise impact awaits the results of advanced models.

Nobre C and Borma L (2009) *Current Opinion in Environmental Sustainaibility,* 1:28-36.

Farewell to GLOBEC

One of IGBP's most high profile and successful programmes, the Global Ocean Ecosystem Dynamics project (GLOBEC), chaired by Ian Perry, finishes in 2009. A book synthesising ten years of GLOBEC research, Marine Ecosystems and Global Change (Barange *et al.*, Oxford University Press, 2010) will be published in 2010.

"GLOBEC has been an outstanding success", said IGBP executive director Sybil Seitzinger. The project brought together the global scientific community to understand the complex dynamic interactions between ocean physics, climate, fishing and ecosystems.

IGBP will continue to build on the success of GLOBEC by expanding the Integrated Marine Biogeochemistry and Ecosystems (IMBER) project. The details of this plan are outlined in a supplement to the IMBER science plan to be published before the end of 2009.

GLOBEC activities have been supported in numerous countries around the world, and those funding agencies are thanked for their role in its success. In particular, the US National Science Foundation and the UK Natural Environment Research Council. The UK's Plymouth Marine Laboratory successfully hosted the international project office, under the direction of Manuel Barange. GLOBEC is sponsored by IGBP, the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC).

See next issue for a feature on GLOBEC science.

To pollute or not to pollute

AEROSOLS – tiny fluid droplets or solid particles suspended in air – are responsible for pollution, and much effort has thus been invested in controlling their atmospheric concentration. But certain aerosols (sulphate aerosols, for example) also hinder the penetration of sunlight through the atmosphere, thereby leading to cooling. Reducing their concentrations may ironically facilitate global warming. So are aerosols good or bad for Earth's climate?

In a short piece published in *Science,* scientists associated with IGBP's Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS) underscore the need for unravelling the influence of aerosols on climate processes. Surveying the results of recent work, Almut Arneth and colleagues (including iLEAPS chair Markku Kulmala) mention that although "the jury is out, the studies available to date mostly suggest that air pollution control will accelerate warming in the coming decades".

To pollute or not to pollute seems to be the rather bizarre dilemma posed by the complex effect that aerosols have on Earth's climate and human wellbeing. Aerosol emissions will obviously need to be controlled to minimise pollution, but Arneth and colleagues suggest that cuts in greenhouse gas emissions will need to be higher to compensate for the warming effects of reducing atmospheric aerosols.

Arneth A, Unger N, Kulmala M, Andreae M O (2009) *Science*, 326:672-673.

Europe dominates alternative quality-of-life index

Human development index (2007)	Alternative index (corrected for per capita CO_2 emissions)
1 Norway	1 Switzerland
2 Australia	2 Sweden
3 Iceland	3 France
4 Canada	4 Iceland
5 Ireland	5 New Zealand
6 Netherlands	6 Norway
7 Sweden	7 Portugal
8 France	8 Italy
9 Switzerland	9 Spain
10 Japan	10 Austria

SWITZERLAND TOPS a quality-of-life index that includes, for the first time, an indication of a country's global environmental impact, or global responsibility.

The index, based on the UN's Human Development Index (HDI), adds a country's carbon emissions into the mix. This new approach considered the top 40 emitters of carbon dioxide, and shows how some countries' high standard of living comes at an environmental price. Compared with the 2009 HDI index, published in October, the US, Australia and Canada perform particularly poorly, dropping in rank from 12 to 39, 2 to 37 and 4 to 36, respectively. European countries tend to fare better in the new system.

Since the 1990s, the HDI has been an immediate and iconic country-by-country snapshot of wellbeing, standard of living and quality of life. But, argues Professor Chuluun Togtokh from the National University of Mongolia, human development is closely intertwined with the health of the environment and a concern for the quality of life of others. When the UN released this year's HDI, Togtokh felt the index lacked an important component that would capture this.

"Some developed countries have high index values, but poor carbon footprints. The index must be corrected," said the land-use specialist and vice chair of the Mongolian global environmental-change committee.

When Togtokh added carbon dioxide emissions per capita to the index, the effect was immediate and informing (see table). One could argue that by contributing (and having contributed) the most to global warming, the developed countries that fell farthest are having the largest impact on the livelihoods of those in other countries, particularly in the developing world – the countries most affected by climate change.

"The index seems an effective tool for reflecting a country's quality of life, while respecting the quality of life of others," reflects Togtokh.

In addition to the GDP, the recent Human Development Index includes two additional parameters: a health indicator, longevity, and education indicators, literacy and the number of children in education. Togtokh added CO_2 emissions. He believes with his index, the new leaders, Switzerland and Sweden, are prime examples for developed countries to show that it is possible to keep human development high and reduce emissions. "Given the importance of equity at the Copenhagen climate negotiations, the index provides a clear indicator of which countries are taking their global responsibility seriously," he added.

But Pep Canadell from the Global Carbon Project points out that while some countries' domestic emissions are encouraging, the index does not take into account a country's emissions due to imported goods made in countries such as China.

Togtokh accepts this is an issue that needs addressing – he says the new index will develop over time – but believes it does not distract from its overall value.

Elinor Ostrom wins Nobel economics prize

THE NOBEL PRIZE for economics was awarded to a former member of the International Human Dimensions Programme's scientific committee, Elinor Ostrom. Ostrom is the first woman to win the prize since it was founded in 1968, and the fifth woman to win a Nobel award this year – a Nobel record.

The award was given jointly to Ostrom and Oliver Williamson for their analyses of economic governance. The Royal Swedish Academy of Sciences said Ostrom's work demonstrated how common property can be successfully managed by groups using it.


J. Lokrantz/Azote

EVENTS

2009

December

7-19. UN Climate Change Conference COP-15. Copenhagen, Denmark.

14-18. AGU Fall Meeting. San Francisco, US.

2010

February

22-23. Greenhouse gases in the Earth system: setting the agenda in 2030. Royal Society, London, UK.

22-26. Ocean sciences meeting. Portland, Oregon. (ASLO, AGU, TOS)

March

16-19. State of the Arctic conference. Miami, Florida. (ARCUS, ISAC, DAMOCLES)

April

7-8. ICSU Geo-Unions. Paris, France.

21-23. Continents under climate change conference. German Foreign Office, Humboldt-Universität zu Berlin, Germany.

26-29. PICES Climate change effects on fish and fisheries: forecasting impacts, assessing ecosystem responses, and evaluating management strategies. Sendai, Japan.

12-13. International symposium on coastal zones and climate change. Monash Unversity, Victoria, Australia. (APN)

May

17-21. Air-water gas transfer conference. Kyoto, Japan. (JSPS, SOLAS)

June

8-10. International Polar Year (IPY) Conference. Oslo, Norway.

13-18. Goldschmidt 2010 - Earth, energy and the environment. Knoxville, Tennessee, US.

Integrated ocean observing system needed

MORE THAN 600 participants from 36 nations met in Venice in October for the OceanObs conference, co-sponsored by IGBP.

The conference resulted in the statement that "Despite the profound importance of marine information to meet the needs of our societies, the resources necessary to observe, assess and forecast global marine conditions are fragile and insufficient." The group wants all governments to commit to international coordination of global biogeochemical and biological observations.

"The global ocean observing system right now is almost purely physical. There are carbon measurements and ocean colour from which we can derive some biological data, but there are very few biogeochemical or biological measurements," said co-organiser, Julie Hall, executive officer of IGBP project IMBER (Integrated Marine Biogeochemistry and Ecosystem Research).

"This conference showed a clear willingness from the physical, biogeochemical and biological communities to work together for an integrated ocean observing system," added Hall.

Clara Natoli

Planetary management project takes off

Planetary ecologist?

White House photo

BARACK OBAMA and colleagues will need help keeping the planet's vital systems stable under the twin pressures of economic and population growth. In December, the International Human Dimensions Programme on Global Environmental Change launched a planetary management initiative – the Earth System Governance project – in Amsterdam to find ways to do just that.

The ten-year scheme will investigate integrated governance systems, from local to global, "that ensure the sustainable development of the coupled socio-ecological system the Earth has become".

www.earthsystemgovernance.org

Health and climate change

HEALTH POLICIES need to gear up to respond to the modifications in disease patterns triggered by a changing climate, says a scientist affiliated with the Intergovernmental Panel on Climate Change. Kristie Ebi of the Carnegie Institution for Science, USA points out that existing healthcare strategies assume a stable climate regime.

Using the incidence of malaria in Africa as an example, Ebi discusses how seemingly minor changes in temperature or precipitation may open up new breeding grounds for mosquitoes, while at the same time reducing the risk of other regions to this infectious disease. Ebi recommends that models used for estimating malaria risks incorporate predictions regarding local/regional climate change.

Ebi K (2009) *Current Opinion in Environmental Sustainability*, 1:107-110.

New vision for international Earth-system science

THE SCALE of global change and the need for closer integration between disciplines has prompted the International Council for Science to develop a new vision for Earth-system science. ICSU (IGBP's parent body) and the International Social Science Council launched an online consultation in the summer followed by an expert meeting in September attended by IGBP chair, Carlos Nobre.

The visioning process will outline key research questions and how to address them. Grand challenges under consideration include increasing knowledge of the coupled human-environment system and developing natural and social observation systems needed to manage the Earth system.

From mid December until mid February the wider community can comment on the draft report from September's meeting. Following this consultation, the next key milestone is a programme co-sponsors' meeting in mid 2010.

www.icsu-visioning.org

International climate research plan published

THE WORLD CLIMATE Research Programme has published its implementation plan for 2010 to 2013. The plan outlines interdisciplinary research and modelling initiatives, a focus on regional climate assessments and climate information for decision-makers.

www.wcrp.wmo.int

A PLANET ON THE EDGE

Maintaining the planet's stable climate would seem like a good idea. Scientists have now identified what they think are the nine Earth systems that do just that. But it looks like we have already crossed three of the boundaries that keep us a safe distance from dangerous thresholds.

In September, Johan Rockström from the Stockholm Resilience Centre and colleagues published an article in the journal *Nature* entitled 'A safe operating space for humanity'.

Rockström argued that our civilisation has thrived on environmental stability: as long as society knew what was coming up it could plan for the future. This easy predictability allowed agriculture to develop then flourish. This helped the global population to swell to six billion people. And it has enabled us to tame our environment. We make the environment work for us on a global scale. In short, we rely on environmental stability to support our society and the economy.

The best available evidence says this stability, which we know has lasted 11,000 years, is now in jeopardy. During this stable period – the Holocene – a range of globally-important biogeochemical parameters fluctuated within a narrow band. In the distant past, large shifts in some of these parameters have been associated with planetary-scale environmental change.

Now, our own burgeoning civilisation is overwhelmingly responsible for pushing some of these parameters beyond the narrow range required to remain in a similar stable state. But how far can we push before we subject ourselves to a catastrophic shift on a global scale? Without humans, the planet's climate would likely stay in this stable state for a few thousand years before slipping into the next ice age. This now looks unlikely. When you look at the problem from this point of view, says Rockström and colleagues, it becomes apparent that the Holocene climate is the desired state for society and the economy.

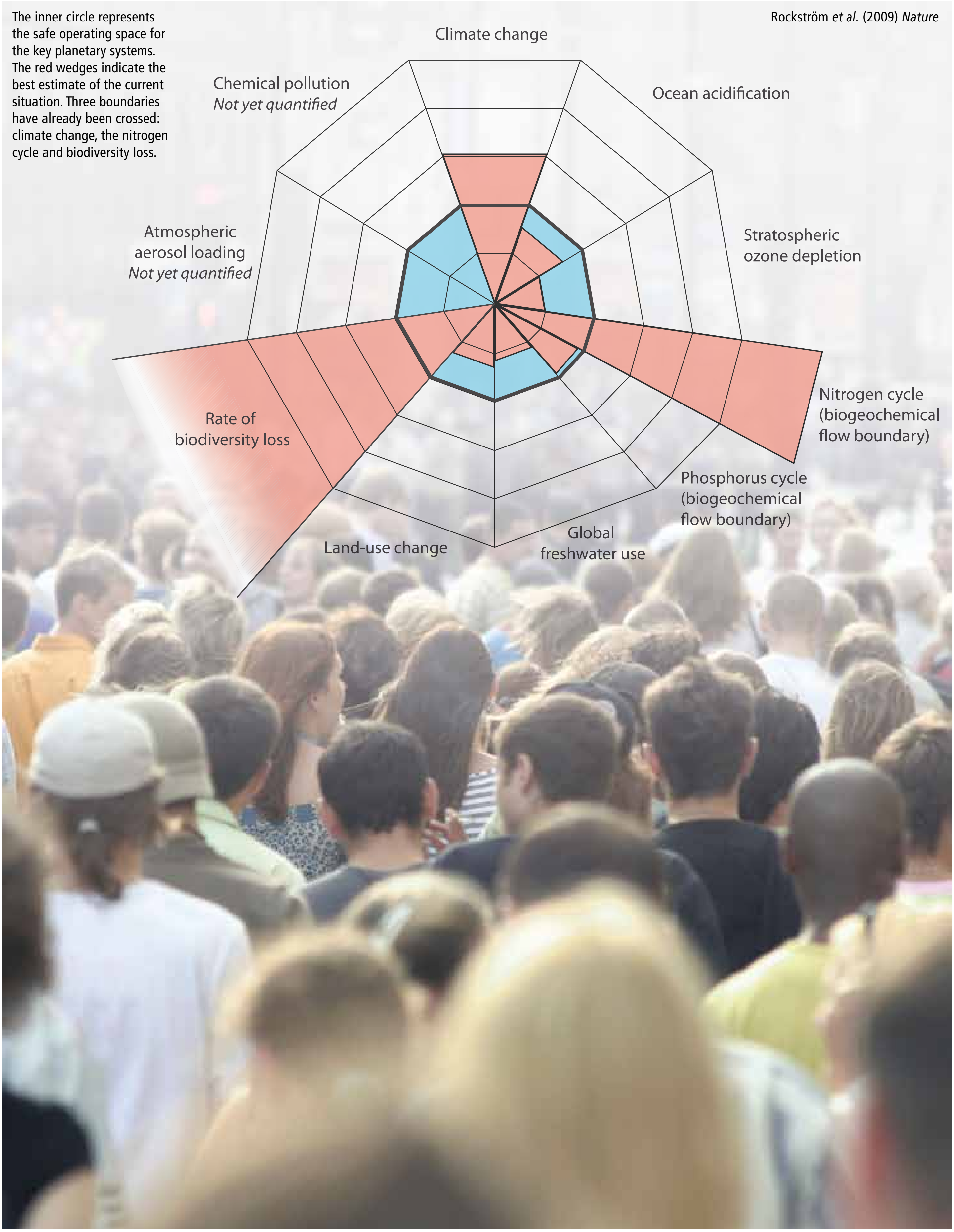
We have overstepped three boundaries.

Stepping out

But we are moving outside of the Holocene envelope. In an astonishingly short period – 250 years – civilisation has generated the capacity to rock the global Earth system in a way it has not been pushed for millions of years. Does our society have the mechanisms to rein this in? Not yet, but the starting point must be to establish what the Holocene's boundaries are, where their limits lie, and then to estimate how close we are to those limits.

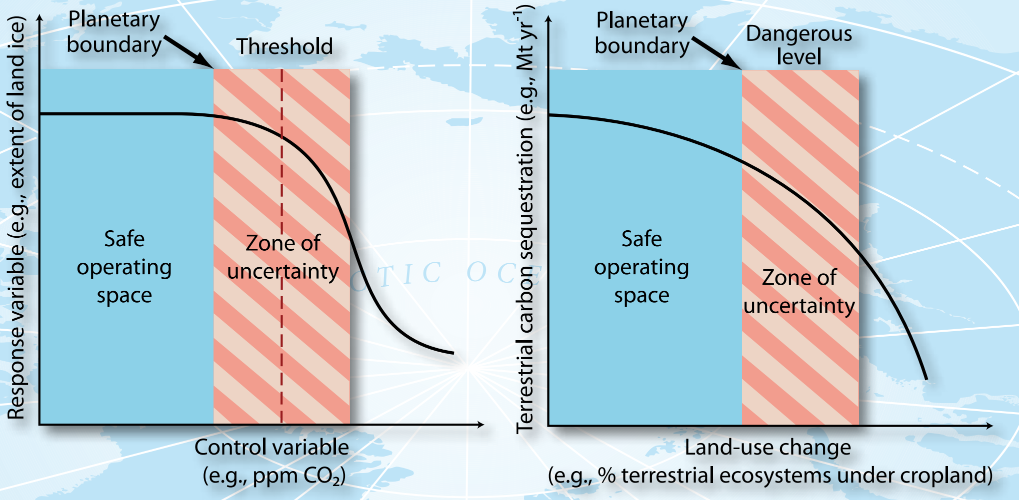
The planetary-boundaries concept has been gestating for several years. Nine of the paper's authors are closely linked to IGBP, including two former executive directors, Kevin Noone and Will Steffen and a former vice chair, Paul Crutzen. IGBP's executive director Sybil Seitzinger and chair Carlos Nobre have also been involved in discussions and workshops. Rockström asked scientists from many disciplines – climatologists, ecologists, oceanographers, land-use specialists, hydrologists and others – "which Earth-system processes must we be stewards of to remain within the desired state?"

The experts identified just nine boundaries: climate change, biodiversity loss, interference with the nitrogen and phosphorus cycles, stratospheric ozone depletion, ocean acidification, global freshwater use, change in land use, chemical pollution and atmospheric aerosol loading. The boundaries are interlinked and the authors suggest we have overstepped three of them: atmospheric carbon dioxide concentration, biodiversity loss and the nitrogen cycle. We are close to the boundaries of a further three: land use, fresh water and ocean acidification.



The inner circle represents the safe operating space for the key planetary systems. The red wedges indicate the best estimate of the current situation. Three boundaries have already been crossed: climate change, the nitrogen cycle and biodiversity loss.

Credit: Istockphoto



Two types of boundary are identified. On the left is a boundary marking the safe limit to avoid crossing a threshold in the Earth system that would cause, for example, ice-sheet collapse. On the right, there is no known threshold but crossing the boundary will lead to large-scale effects of serious global concern.

Rockström *et al.* (2009) *Nature*

Early days

The nine boundaries and their suggested limits define a "safe operating space for humanity". The authors stress that this work is still preliminary, some of the thresholds need closer investigation to improve estimates, and two, aerosols and chemical pollution, have no limits yet imposed. There is simply too little information to make estimates.

The estimates for seven of the boundaries are possible because of the tremendous effort by the international research community over the last few decades to understand the planet's biogeochemical cycles and how these cycles have changed throughout Earth's history.

One upshot of this research is the knowledge that the planet's response to major changes is non-linear. Take glaciers, for example. As atmospheric carbon dioxide levels increase they react in a relatively limited way for a long time before reaching a threshold, then they can melt rapidly. The exact position of a threshold is extremely difficult, if not impossible, to pinpoint. So, a planetary boundary is the safe level, based on the best available evidence, beyond which you don't want to transgress for fear of crossing the threshold. "We have put this boundary at the lower edge of the uncertainty level around this threshold," says Rockström.

The *Nature* feature concludes, "The evidence so far suggests that, as long as thresholds are not crossed, humanity has the freedom to pursue long-term social and economic development."

But the conclusion drawn from the longer paper in *Ecology and Society,* upon which the *Nature* paper is based, is bleaker. The complexities and interconnectedness of the dynamic Earth system makes it remarkably resilient to external pressure, even the massive pressure we now exert. But this is lulling us into a false sense of security. "Incremental change can lead to the unexpected crossing of thresholds that drive the Earth system, or significant sub-systems, abruptly into states deleterious or even catastrophic to human well-being."

If you are heading for an abyss wearing a blindfold, you should stop the car.

Some critics

The idea of interlinked boundaries when framing the planetary-scale challenges facing humanity is an interesting and powerful concept that changes how policymakers can address the problem. But it is not without its critics.

Setting boundaries for policymakers can allow potentially indefinite slow degradation, argues William Schlesinger from the Cary Institute of Ecosystem Studies in New York. Schlesinger also says the cap on phosphorus is too lenient. "If we cross a threshold for phosphorus that leads to deep-oceanic anoxia, we risk a truly dire situation."

The land-use boundary – no more than 15 percent of the global ice-free land surface should be converted to cropland – has also come under fire. Stephen Bass from the International Institute for Environment and Development in London suggests a limit on soil degradation or soil loss would be a more useful boundary because there is a big difference between intensive and more sustainable farming techniques. But Rockström *et al.* argue that land-use change can trigger rapid continental-scale changes. For example, IGBP chair Carlos Nobre and colleagues believe there is strong evidence that as more of the Amazon rainforest is turned over to cultivation and grazing, eventually a threshold will be crossed that transforms the basin to semi-arid savannah (see news page 7). This would likely have consequences for the Earth's climate system. So, perhaps soil degradation should be an additional boundary.

Setting the climate boundary at 350 parts per million CO_2 is arguably the most contentious. Myles Allen from the University of Oxford argued in *Nature,* and at a recent IGBP/Royal Swedish Academy of Sciences Stockholm symposium, that this boundary misses the point. CO_2 should be viewed as a non-renewable resource. To avoid dangerous climate change we should stop emitting carbon to the atmosphere once we reach one trillion tonnes. Michael Raupach from the Global Carbon Project points out on page 24 that, if this is the limit, we have just passed peak CO_2.

The annual freshwater consumption boundary of 4000 cubic kilometres could well be too high. More consensus is needed on extinction rates, set at ten species per million per year. And the chemical pollution boundary may prove impossible to figure out – there are up to 100,000 chemicals on the global market.

While researchers have been critical of the detail, the boundaries concept has had a positive reception, particularly regarding consequences for policy. Bass says, the "paper has profound implications for future governance systems." He argues it offers some of the wiring needed to link global and national economic governance with governance of natural resources.

Inadequate governance

In recent years, the environmental science community at all levels has been asked to make its outputs more policy relevant. An upshot of this, for example, has been a major drive on climate-change research focused on local-to-regional space scales and timescales of days to decades. Policy, it is believed, works more effectively at these scales.

But the boundaries concept appears, on the face of it, to take us back to the global. The authors say current governance systems are often oblivious to or lack a mandate to act on planetary risks, despite evidence that pressures on biophysical processes of the Earth systems are accelerating.

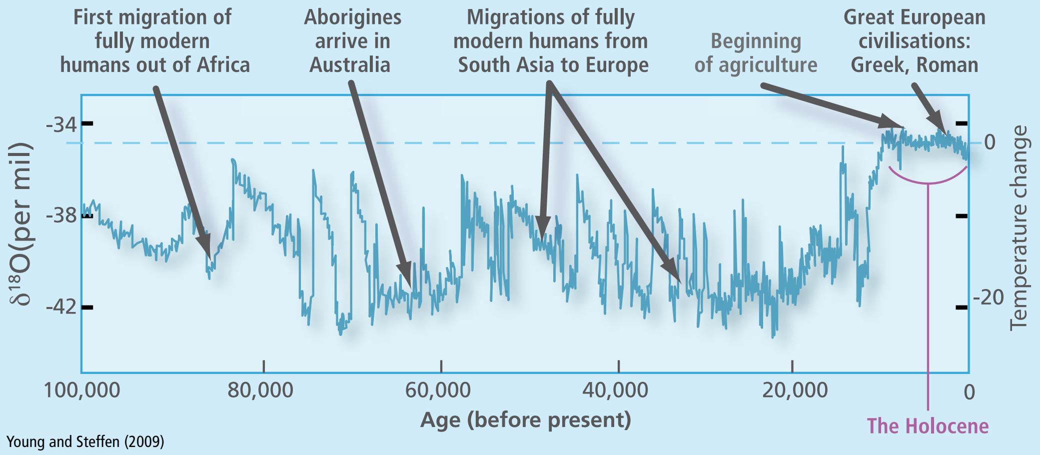
If the planetary-boundaries concept proves sound – further analysis from a larger community is required – it throws down the gauntlet to policymakers. The paper suggests in no uncertain terms that governance systems are inadequate to address the scale of the problem, not just at a planetary level, but also at regional and local scales. This is why the planetary boundaries concept may prove so attractive: governments prefer dealing with boundaries than uncertainties.

UN Secretary-General Ban Ki-moon told the World Climate Conference in Geneva in August that we have our foot on the accelerator and we are heading for an abyss. At the IGBP symposium in September, Rockström responded that if you are heading for an abyss wearing a blindfold, you should stop the car.

Written by OWEN GAFFNEY.

Governments prefer dealing with boundaries.

HUMAN DEVELOPMENT AND GLACIAL-INTERGLACIAL CYCLING



Young and Steffen (2009)

PLANETARY BOUNDARIES

Earth-system process	Parameters	Proposed boundary	Current status	Pre-industrial value
Climate change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387	280
	(ii) Change in radiative forcing (watts per metre squared)	1	1.5	0
Rate of biodiversity	Extinction rate (number of species per million species per year)	10	>100	0.1-1
Nitrogen cycle (part of a boundary with the phosphorus cycle)	Amount of N_2 removed from the atmosphere for human use (millions of tonnes per year)	35	121	0
Phosphorus cycle (part of a boundary with the nitrogen cycle)	Quantity of P flowing into the oceans (millions of tonnes per year)	11	8.5–9.5	-1
Statospheric ozone depletion	Concentration of ozone (Dobson unit)	276	283	290
Ocean acidification	Global mean saturation state of aragonite in surface sea water	2.75	2.90	3.44
Global freshwater use	Consumption of freshwater by humans (km^3 per year)	4000	2600	415
Change in land use	Percentage of global land cover converted to cropland	15	11.7	low
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis	to be determined		
Chemical pollution	For example, amount emitted to or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in the global environment, or the effects on ecosystem and functioning of the Earth system	to be determined		

Boundaries for processes in red have been crossed. Data source: Rockström *et al.* (2009) *Nature*

Further information
www.nature.com/news/specials/planetaryboundaries/index.html

Video
Johan Rockström's presentation at the IGBP-KVA symposium Planet Under Pressure
www.igbp.net

Johan Rockström
www.stockholmresilience.org

CLIMATE CHANGE IN A NUTSHELL

Can the complexity of the Earth's climate be distilled down to a single number like an economic index? The IGBP climate-change index does just that and it seems effective at exposing underlying trends.

Wherever you are in the world this scene will be familiar. You are watching the news on TV. Towards the end of the bulletin, before the weather, the newsreader says "and now it's time to go to the markets". Then some numbers flash up on the screen. It could be the Dow Jones index, the FTSE, the Nikkei, the DAX or the Hang Seng. Whichever one it is, the message is instant and clear: the economy is growing, it is shrinking, or it is stable. And you get a visual clue as to the rate of change too.

Economic indices like the Dow Jones are extremely powerful communications tools. The single number, distilled from perhaps hundreds of sources, combines a wealth of underlying information. The underlying data are essential to professionals in the field, but they are an unnecessary distraction to most others. The media stops at the index, only delving deeper when the markets crash or soar: most people are not interested in the detail.

Economic theorists argue how inaccurate these economic indices are for predicting economic trends, but nevertheless the press, the public, policymakers and economists follow them daily. They are easy to digest, and give a simple thumbs up/ thumbs down assessment of economic trends.

Given the incredible complexity and interannual variability of the Earth's climate, you might reasonably argue there is no way this overall trend could be distilled down to a single number. But such a number could be useful. Many of the key parameters – temperature, sea level, Arctic sea-ice extent – vary naturally each year. The underlying trend is not always so clear to the casual observer. An index could expose the underlying trend and visually indicate if climate change is accelerating or slowing. This is the idea behind the IGBP climate-change index. It works like the famous economic indicators and gives the press, the public and policymakers a visual summary of the trajectory of climate change.

The index removes natural variability extremely effectively.

The index brings together the key parameters from the atmosphere, ocean and cryosphere: atmospheric carbon dioxide levels – the main driver of change – global surface temperature, sea-level rise and summer Arctic sea- ice extent. In doing so the index provides a compelling snapshot of which direction we are heading, and how fast.

The idea came about when several IGBP scientists, including Steven Running, former IGBP director Kevin Noone, Kathy Hibbard, Mark Stafford Smith, IGBP executive director Sybil Seitzinger, Peter Cox, Suzi Kerr and Pierre Friedlingsten, realised that the way various global datasets are reported throughout the year is confusing. It is uncoordinated, there is a variety of unfamiliar units, and natural variability sometimes masks a trend. The press and public are not clear about the scale of the changes scientists are witnessing. The index is a response to these concerns.

Why those four metrics? Steven Running from the University of Montana says, "The iconic Mauna Loa atmospheric CO_2 concentration was obvious. Global air temperature is already widely reported at the end of each calendar year, so that was a logical choice too.

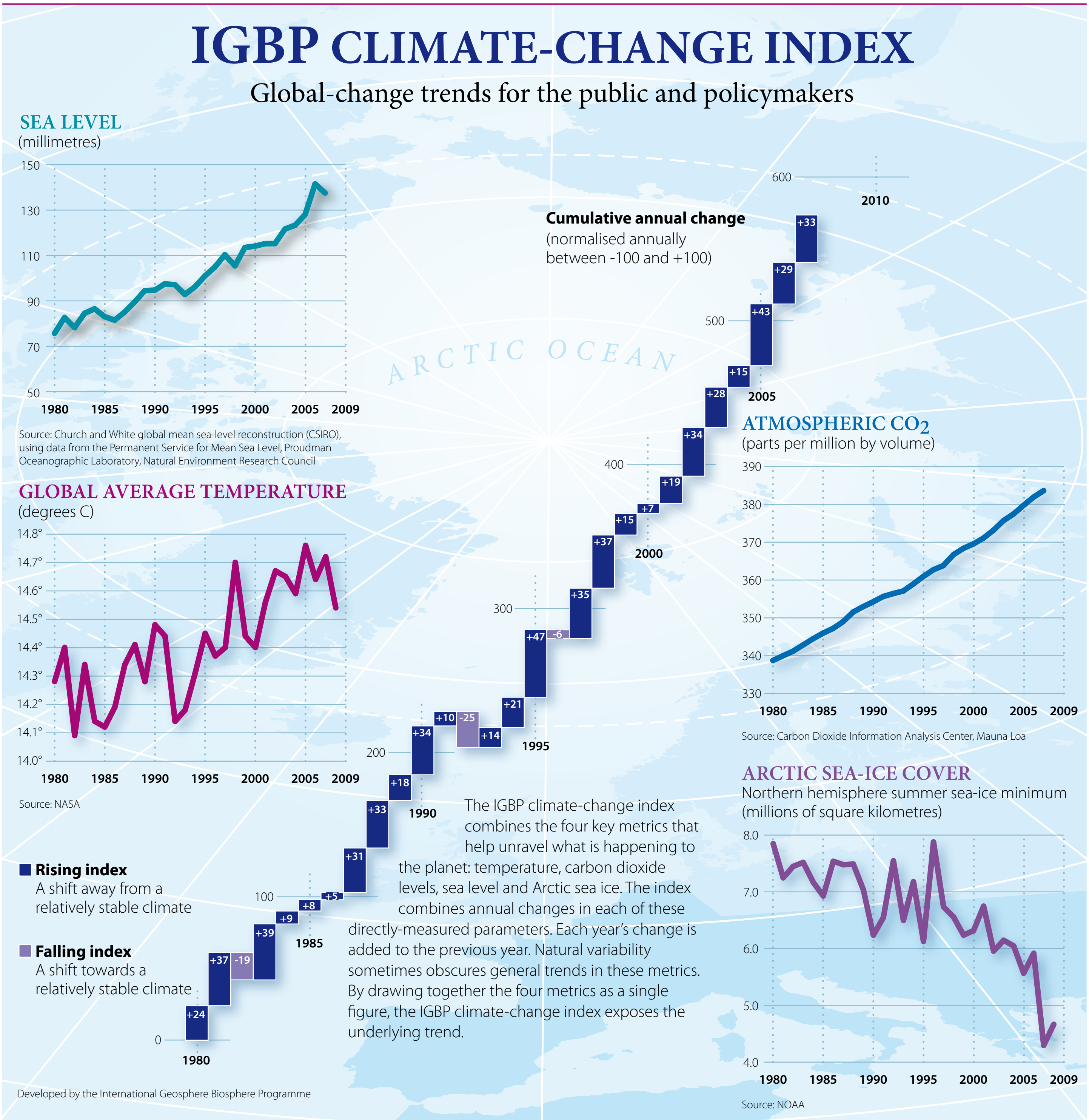
"We needed an oceanic measure and chose sea-level rise because the impact is global and of high public interest. Growing concern about the rate of loss of summer sea ice in the Arctic led us to choose this metric. This parameter broadly represents the Earth system and it is interesting that the summer sea ice extent is shrinking much faster than models predicted five, ten years ago."

In the future, other variables could be added. "We did not identify any good land surface variable, because no good standard exists," says Running. "But some day we may have annual albedo or land-cover change."

Number crunching

The index displays yearly *change.* So even though sea ice is reducing and the other parameters are increasing the index shows that every year, we are moving rapidly away from a nominal 1990 level – chosen because 1990 is the baseline for emissions reductions under the Kyoto Protocol.

Each parameter is normalised between -100 and +100. Zero is no annual change. One hundred is the maximum-recorded annual change since 1980. The param-



eters are added together and averaged. This gives the index for the year. The value for each year is added to that of the previous year because we are talking about cumulative change.

Running says, "Some of us thought we'd need a five-year rolling average to help dampen fluctuations and to elucidate core trends. But when we first produced the index it was obvious this was unnecessary: the index removes natural variability extremely effectively." The index shows that, since 1980, the rate of annual change is steadily increasing. The index decreased in value for just three years in the 30-year period: 1982, 1992 and 1996.

There is growing international interest in the index. IGBP will publish it annually and promote it to policymakers, government departments, the public, the media, organisations such as WWF and schools. It will be available on the IGBP home page and as a PowerPoint slide, and we will ensure easy access to the underlying data.

Requests have also come in to backdate the index 100 years, maybe even 1000 years or more. Probably the first development, though, will be an index on extreme events.

Economic indices like the Dow Jones are extremely powerful communications tools.

Written by OWEN GAFFNEY

A vision for our planet

Tired of hearing the planet is going to hell in a handcart? With concerted planetary management, and a strong vision, the future could be bright – for everyone, says Jill Jäger.

In 2050, the nine billion people living on Earth have found a way to manage the planetary system effectively. Hunger and poverty have been eliminated. Everyone has access to adequate food, clothing, housing, healthcare, education, energy, clean water and sanitation. Under-fives no longer die from preventable disease or endure heavy-metal exposure. The elderly do not die from cold or heat exposure.

In 2050, everyone participates fully in society and has equal opportunities. Human health is no longer considered outside of the health of the ecosystems in which people live. Ecological awareness is an integral part of the education system. People respond effectively to social and environmental hazards and societies care and provide for the most vulnerable amongst them.

The economic system has shifted from "growth"-oriented to "development"-oriented. Carbon dioxide management is under control. Energy efficiency is the norm. The few remaining rainforests have been preserved as global lungs and sinks. The acidity of the oceans is falling. Coral reefs are recovering. Fish stocks are thriving. Global biodiversity loss has stopped accelerating.

Hunger and poverty have been eliminated.

Is any of this really possible? How can our complex social and economic systems interact with a complex planetary system undergoing rapid change to create a future we all want?

In October 2008, as part of an IGBP Fast Track Initiative, a group of economists, sociologists, historians, ecologists, climatologists, oceanographers, biogeochemists, biologists, chemists and others met in Lund on the southern tip of Sweden to draw up a vision for the planet in 2050. What you have just read is the beginning of that vision. But how to get from here to there?

The planet in 2010

Before thinking about the 2050 vision, we took stock of where we are today. While people often talk about massive changes since the start of the industrial revolution in 1750, the pace of change in the last 50 years, the last two generations, is truly unprecedented.

At the start of the industrial revolution the population was just under 800 million. By 1950, it hit 2.5 billion. In July 2008, we reached 6.7 billion. Now, nearly half of the land surface has been transformed by direct human action. More nitrogen is now fixed synthetically for fertilisers and through burning fossil fuels than is fixed naturally in terrestrial ecosystems. Between 1970 and 1997, the global consumption of energy increased 84 percent. In the last 150 years, we have exhausted 40 percent of the known oil reserves, which took several hundred million years to generate.

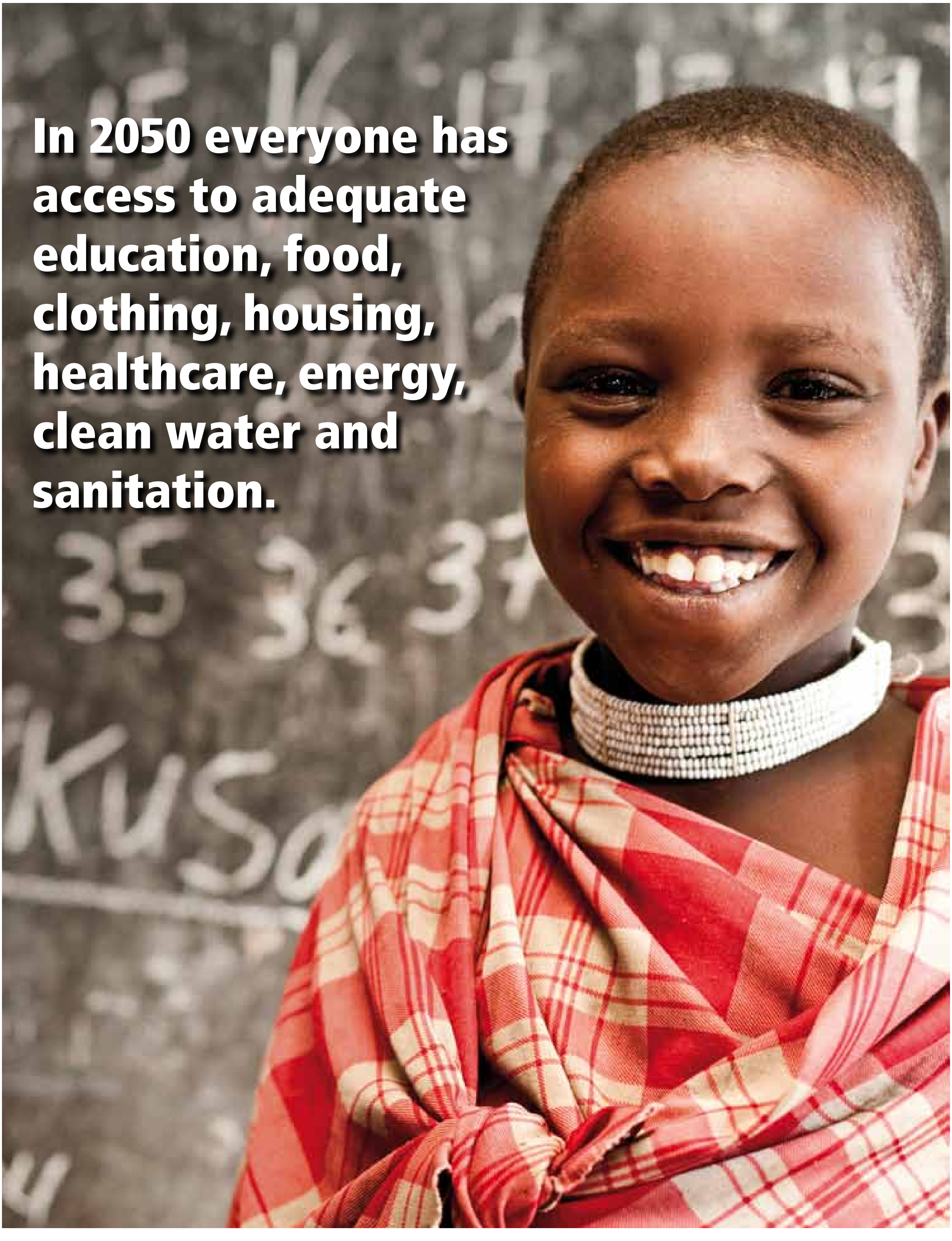
Humans appropriate more than half of all accessible fresh water, and are depleting underground water resources rapidly. Nearly one quarter of recognised marine fisheries are overexploited. About 44 percent more are at their limit of exploitation.

The global economy and human behaviour are driving massive changes on a planetary scale. Our analysis of the state of the planet in 2010 presents a picture of overuse of natural resources, environmental degradation at local, regional and global scales and weak governance.

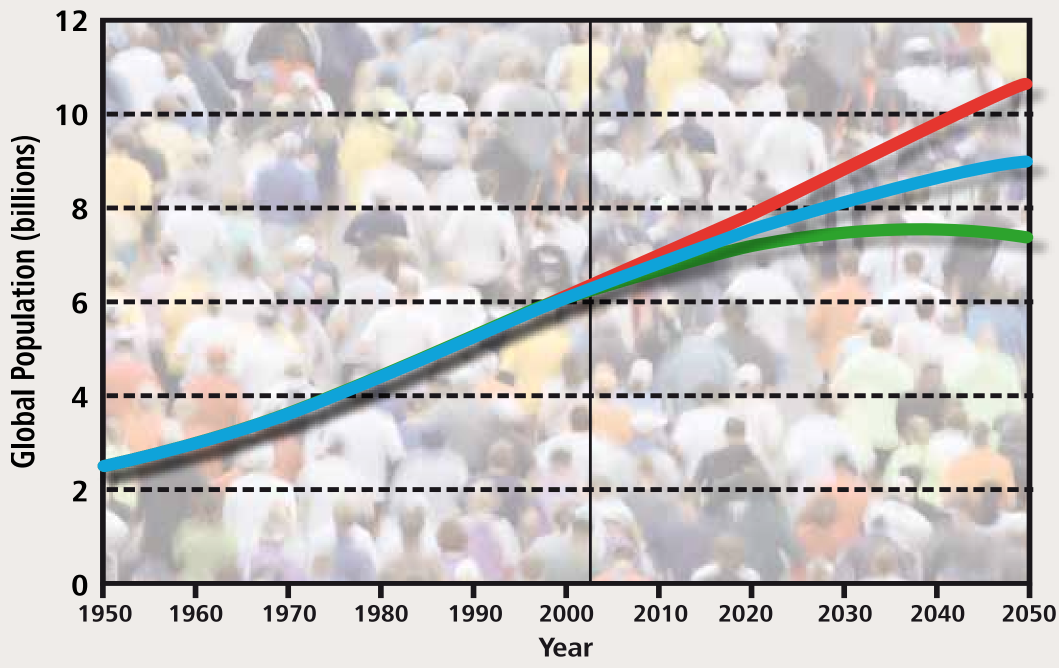
There is no one-size-fits-all solution to the variety of problems listed above. The world is a diverse place. From coral reefs, to fisheries, to forest management, to agriculture, rangeland and rural and urban environments, society has so far responded through partial solutions to specific problems without a systematic and careful consideration of impacts or effectiveness. People depend on the natural world, but integrated solutions that acknowledge the innate coupling between people and the environment have been rare.

The vision for 2050

Let's return to the vision for 2050 before exploring how to get there. The Lund workshop went beyond thinking of the environment and how society exerts pressure on it. The meeting identified



Credit: Istockphoto



United Nations population projections, indicating low, medium, and high range estimates.

peace, non-violence, democracy, social justice and global equity as the defining values of societies. In 2050, the dignity of people and integrity of nature underpin decision-making at all levels. Transparency, accountability, openness, inclusiveness and participation are the defining characteristics of governance processes so that policies are effective and coherent across levels and sectors. The decision-making process itself is characterised by mutual learning (science and education have considerable roles), cooperation and dialogue.

The new economic system values all the diverse kinds of capital and wealth (social, human, cultural, biological, social, infrastructural and physical) as the core assets of society. The indicators used to track progress in development have expanded greatly and include qualitative and quantitative measures of all these types of capital.

Revolutionary transformations of our energy system – from fossil-fuelled to carbon-neutral – have taken place, in parallel with aggressive improvements in energy efficiency. There is now universal access to modern energy services to meet basic needs brought about by new technology and changes in lifestyles.

Our analysis presents a picture of environmental degradation and weak governance.

In 2050, society has struck a balance between humans' needs for fresh water and nature's own needs, through an integrated land and water governance and management approach. At the same time, air pollution in cities has fallen although there are still hotspots of poor air quality.

The oceans have received far more recognition in global environment governance and the acidification trend of the 20th and early 21st centuries has been reversed. On land, the few remaining rainforests, in the Amazon, the Congo and in South-east Asia, are preserved. Forest systems worldwide are managed to increase their capacity to perform as global carbon sinks.

In 2050, approximately two-thirds of the world's population lives in cities and towns. From a global perspective there is a more balanced distribution of small, medium and large urban areas. The cities and towns of 2050 have creative, vibrant and diversified economies that contribute to the well-being of all of the population. The citizens enjoy better health. Food and water security as well as personal security have improved. Urban areas provide opportunities for living, caring, working, recreation and communication. The pressures of urban areas on the Earth system have been considerably reduced.

The pathways from 2010 to 2050

No one denied the vision for 2050 was ambitious. Achieving it required concerted action and change along five pathways: governance, the global economy, knowledge and education, creativity, and value and belief systems.

The **governance pathway** involved recognising and empowering people as citizens and strengthening cosmopolitanism. It was recognised that global issues had to be addressed through new forms of democracy based on acknowledging the universal rights of global citizens. Governance transitions were supported by creating a shared normative framework that included a well-established human rights framework, international environmental law and policy, and a consensus on desired objectives for environment and human well-being. Institutions and governance processes were made to recognise citizenship, responsibility and equitable opportunity. Citizenship took on a global, in addition to a national, meaning. A fundamental shift away from adversarial systems to consensus-building through dialogue was central in making governance transitions.

Along the **global economy pathway**, the new development model was based clearly on the goal of development not as economic development but as improvement in human well-being in line with sustainable development. The new model focused on sufficiency of material consumption, whereby consumers considered their needs rather than their wants, so controlling material consumption. Rather than measuring progress by GDP, the new model used measures of improvement in human well-being and environmental and social sustainability.

A central strategy in the **knowledge and education pathway** was the conscious promotion of a set of values that placed central importance on care for the lives and experiences of people, other species and the ecosystems in which they live. The educational system was transformed to ensure a balance of building values and developing every person's intellectual, emotional, social, physical, artistic, creative and spiritual potentials.

The **creativity pathway** built on changing patterns of behaviour and new forms of media already visible in the early 21st century, such as the increasing use of the internet. These provided opportunities for greatly expanding the positive role of creative expressions for societal change. This celebration of creativity in all its diverse forms became a tool in the intercultural communication. The focus on creativity, and the associated attention this gives to inner well-being, helped to redefine notions of success, moving it from material wealth to a more inclusive approach of fulfilment related to spiritual and moral values as well.

Simply giving people facts about the speed of global change alone does not always convince them to change behaviour. Change comes about by aligning new ideas with people's core beliefs and values. By 2050, religious organisations became strong voices for a shift towards an ecological, well-being culture and so making a significant contribution in shaping the **values and beliefs pathway.**

During the workshop in Lund, southern Sweden, delegates visited sustainable developments in the surrounding region, Västra Hamnen (Western Harbour), a leading international example of sustainable city development and the ecologically designed Augustenborg.

Back to reality

The workshop participants demonstrated clearly that the state of the planet in 2010 is far from satisfactory. Their vision for 2050 is truly ambitious and sets a goal that should provide a focus for **discussion by society**. The pathways to the vision are equally ambitious and demonstrate the kinds of deep structural change that will be necessary. Achieving an equitable and sustainable future will require **strong leadership** supported by and even pushed by a society that is fully aware of the need for change and willing to accept some of the inevitable trade-offs. There are small examples of the kinds of transition that are needed to achieve the 2050 vision already being implemented. These must be nurtured, copied and strengthened through learning from experience until they become the mainstream. ▮

JILL JÄGER is an independent scholar in Vienna, Austria. She was executive director of the International Human Dimensions Programme between 1999 and 2002.

The economic system has shifted from "growth"-oriented to "development"-oriented.

The results of the Planet in 2050 workshop will be published in a book entitled *The Planet in 2050 - The Lund Discourse of the Future*. The workshop was an International Geosphere-Biosphere Programme fast-track initiative.

SPONSORS

City of Lund

City of Malmö

Earth System Science Partnership (ESSP)

European Science Foundation

Heinz

International Geosphere-Biosphere Programme

International Institute for Industrial Environmental Economics at Lund University (IIIEE)

LMK industri

Lund University

Mossagården

National Center for Atmospheric Research (NCAR)

Natural Environment Research Council's QUEST programme (Quantifying and Understanding the Earth System)

Region Skåne

TRACKING CHINA'S URBAN EMISSIONS

China's vast cities are hungry for energy. **Shobhakar Dhakal** discusses emissions with **Owen Gaffney.**

China is now the number one emitter of carbon dioxide, according to the Global Carbon Project. Its 1.3 billion people contribute five percent of the world's gross domestic product and 15 percent of global primary energy demand. But because of a heavy reliance on coal, this equates to 19 percent of global carbon dioxide emissions.

All indicators suggest these statistics, alongside rapid economic growth, are rising sharply and show no sign of slowing. The challenge of controlling these emissions starts with an accurate knowledge of where they are coming from. Shobhakar Dhakal, an energy expert and one of the two executive directors of the Global Carbon Project, has made the first estimate of China's urban energy use in close collaboration with the International Energy Agency.

First, what did you discover about China's urban energy use?

We found that 84 percent of China's commercial energy use is from urban areas, and China's 35 largest cities contribute 40 percent of its CO_2 emissions. Throughout the 1990s it looks like China made rapid progress in reducing the carbon intensity of its economy. But, alarmingly, progress has either slowed or reversed recently.

Across the 35 largest cities, did any patterns emerge?

Yes. Three groups emerged. Cities like Beijing, Shanghai, Guangzhou and Fuzhou have adopted a relatively low-energy consumption but high economic output model. These cities are close to China's coast, the climate is warmer and service industries tend to dominate.

Cities like Xining, Yinchuan,

Dawn over Shanghai

Credit: Istockphoto

Guiyang, Hohhot and Urumqi are farther inland, cooler and contain more energy-intensive industries. These are the big emitters. They are basically less developed than the coastal regions. These cities will be flashpoints of tension when it comes to reducing emissions. The third group falls between these two models.

How quickly have coastal cities moved to a less carbon-intense energy model?

For Beijing, between 1985 and 2006 coal's share of emissions declined from 58 percent to 26 percent. In Shanghai and Tianjin this was 51 percent to 18 percent, and 61 percent to 33 percent, respectively. These are rapid transitions. But this treats electricity as a separate source of emissions. When you count electricity, which mostly comes from coal, such transitions are slower.

I thought natural gas would play a larger role than it does. Beijing and Chongqing have increased their natural gas infrastructure. It forms 4.9 percent and 8.2 percent of their energy systems, respectively. But Shanghai and other cities have not really improved their share of natural gas significantly. I conclude the shift to cleaner fuels is not significant and it has not contributed to the dampening of CO_2 growth despite the perceived impression that the role of natural gas is expanding rapidly in Chinese cities.

Increasing urbanisation is a national priority in China. Does China have a wish to reduce emissions?

China has put a great deal of effort into energy security. Lots of China's efforts at energy efficiency are not to do with climate change, they are to do with energy security, and, at a local level, to control air pollution. However, these will improve carbon performance in general.

Given the speed of economic growth, Chinese cities fail to reduce emissions in all key sectors: commercial, household and transport systems.

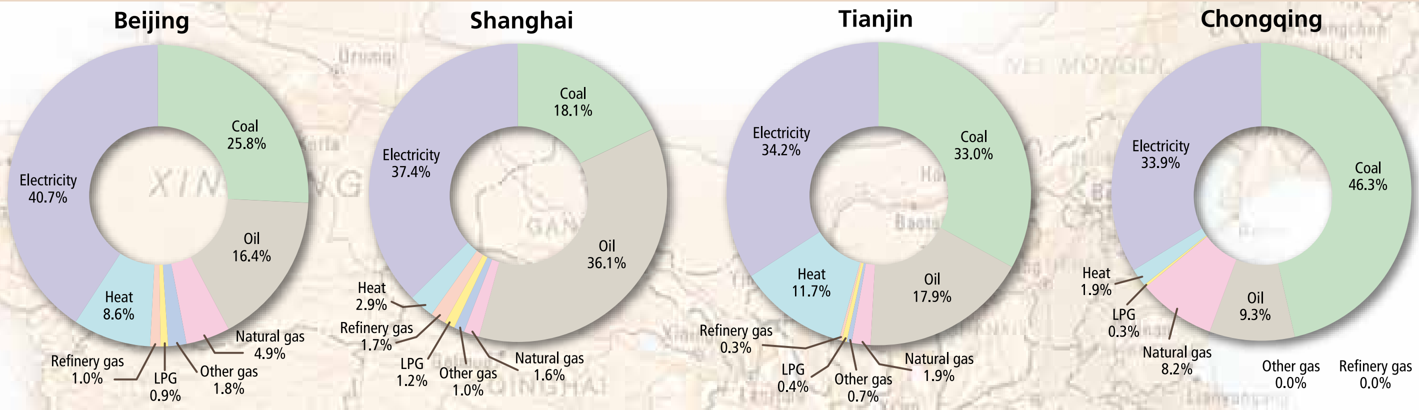
84 percent of China's commercial energy use is from urban areas.

How can China start reducing its emissions?

In the past, even very senior government officials of what was SEPA (now Ministry of the Environment) openly complained that cities compete with each other to attract direct foreign investment and are paying very little attention to the environment. Cities are not serious about reducing emissions as of yet.

National government really needs to provide some comprehensive guidelines for improving the carbon performance of

Contribution of various fuel types in energy-related CO_2 emissions in 2006.



Key indicators and estimated energy and CO_2 of China's 35 largest cities, 2006

	China	35 cities	35 cities' contribution
Total population, million	1314	237	18%
Gross Regional Product (marketprice), billion US $	2719	1109	41%
Total commercial energy consumption, million TJ	65.7	26.2	40%
Per capita commercial energy consumption, MJ/person (registered permanent population)	50,000	110,771	2.2 times more
Per capita GDP/GRP, US $/person (registered permanent population)	2068	4681	2.3 timesmore
CO_2 emissions (commercial energy-related), million tonnes	5645	2259	40%
Per capita CO_2 emissions (commercial energy-related), tonnes/person	4.30	9.54	2.2 times more

Sources: Calculated from base data of China Statistical Yearbook (2007) and China Energy Statistical Yearbook (2007).

urban development. They need to provide incentives for cities to optimise urban energy efficiency. The urban planning, building and transport sectors need to grow in a more integrated way, so the total energy demand for the city is reduced.

I think an initial step is an overarching national system providing comprehensive guidance to cities. This is weak right now. Second is to get numbers right. City energy and carbon accounting are not done by cities, and basic information for cities other then big ones is obscure. Proper accounting, scenario analyses and identifying alternative low-carbon pathways are key.

Beijing's emissions from transport have seen a sevenfold increase between 1985 and 2006? What is being done to address this?

Basically little has been done. Whatever they have done they have done for energy security and air pollution.

These cities will be flashpoints of tension when it comes to reducing emissions.

Beijing is perhaps a less industrial city compared with Shanghai. But it is also more highly motor dependent. A great benefit of the Beijing Olympics was that it extended the subway system and improved other public transport modes such as regular bus services, Bus Rapid Transit systems and integrated transport planning. The policy initiatives aimed at reducing the supply and demand of private motorised transportation are, however, weaker. One such weak policy I see is parking supply and cost which could have much stronger potentials. Road pricing, similar to Singapore and London, could yield good results.

Shanghai's transport emissions shot up tremendously in the same period, despite much stronger control over vehicle ownership and use in the city. The Shanghai authorities have restricted the number of licence plates issued each year. To register a car you have to bid in an auction for a restricted number of licence plates. But there is a lot of pressure to abolish it.

Are there any underlying patterns going on in these cities?

Yes, there is some sort of structural shift happening. If you look at the manufacturing sector, its share of CO_2 emissions is going down, but the transport sector is going up. Motor vehicles are on the rampage. People are getting rich. They have more money in their pockets and they are all buying cars.

Is there an ideal model they could follow?

I think one city cannot be a full model to another given that all cities are different social, political, cultural, geographical, economic and infrastructure settings. However, big Chinese cities should be able to look at the Tokyo model for public transportation and mixed land uses. The way the public transport has been developed in Tokyo is quite amazing. It is so good no one thinks about using the car.

How does your analysis of Chinese urban areas, particularly megacities (population greater than ten million), compare with the rest of the world?

We have shown that the larger cities have a disproportionate influence on China's economy and energy use. While they house just 18 percent of the population, they produce 41 percent of GDP and contribute 40 percent of CO_2 emissions (in 2006). This counters the argument that larger cities are getting unfair attention. The opposite in fact, we show that large cities should be the primary target for improving energy security and climate-change mitigation to start with.

Our work on four megacities, Beijing, Shanghai, Tianjin and Chongqing, revealed a number of interesting facts. Energy use and CO_2 emissions have increased several-fold in the last two decades, with the industrial sector contributing the most. While we show that the average per capita urban energy use of China is small, in the case of the megacities, it is huge. In Beijing it is 11.9 tons per registered person a year, Shanghai is 16.7 tons and Tianjin, 12.4 tons. These figures are well above other key cities. Tokyo is 5.9 tons, Greater London 6.9 tons, New York 7.1 tons. The common wisdom that per capita emissions of developing countries are far smaller than developed countries does not seem to hold true for megacities at least. I must also mention that comparing cities is a complex issue – they can be compared with multiple viewpoints and multiple definitions of carbon responsibilities.

Dr Shobhakar Dhakal is executive director of Global Carbon Project's Tsukuba International Office, based near Tokyo, and leads the Global Carbon Project's Urban and Regional Carbon Management (URCM) Initiative, set up in 2005. He also works closely with ICSU's other global environmental change programmes such as the International Human Dimensions Programme, and contributes to several global assessments.

What are the key steps China needs to take?

Reduce reliance on coal and move to new technology, such as clean coal technology and carbon sequestration from power plants, if coal cannot be avoided in the medium term. But the second important aspect is to try to address the city as a place where carbon optimisation can be done. In China, everything is looked at from the national perspective and a very much sectoral perspective. So not much thought is going into how to optimise the urban system as a whole, and how they can develop low-carbon cities. Those kinds of approaches are not being discussed as much as they should be.

But our analysis showed that, in 2006, the urban contribution to China's total commercial energy use was 84 percent (similar for energy-related CO_2 emissions). Given such a high contribution, the ratio between urban and rural contributions is huge: 6.8. Similarly, the ratio of urban to national per capita commercial energy use is 1.9. Since the per capita energy use in highly urbanised cities is rising and the rate of urbanisation itself is itself rapid, it is inevitable that the urban contribution will increasingly determine China's energy use and CO_2 emissions for the next few decades. China needs a comprehensive national strategy for integrated planning for urban development and energy efficiency. This is especially important because urban development led by individual cities in China has been rampant with little thought for environmental considerations and climate-change mitigation.

My take on Chinese policymakers is that they want to address the climate issue sincerely.

You are involved in a high-level policy advisory body providing information straight to the Chinese government. Are you optimistic about change?

Yes, I am part of a task force on energy efficiency and urban development (China Council for International Cooperation for Environment and Development). I have also closely communicated with many Chinese colleagues in this area for several years and, if my sample is not biased, most of my Chinese colleagues are very optimistic. Reducing CO_2 emissions is one tough issue but I see strong prospects and willingness to dampen the growth rate of emissions. I am happy to see a positive mood in the scholarly community. Commitment in political negotiations is another matter altogether.

My take on Chinese policymakers is that they want to address the climate issue sincerely. But it is difficult for them to commit and express this openly for fear of being pushed into a corner in the face of international pressure. The need for economic growth is hard to deny and balancing it with climate concerns is something we need for humanity's quest for survival. ▮

MORE INFORMATION

Urban energy use and carbon emissions from cities in China and policy implication, *Energy Policy*. Shobhakar Dhakal 2009.

HAVE WE REACHED Peak CO_2?

Emitting a total of no more than one trillion tonnes of carbon to the atmosphere will give humanity a 50 percent chance of keeping global warming to 2˚C above preindustrial temperatures. If this is the goal, we have just passed peak CO_2, says **Michael Raupach**.

Perhaps half a million years ago, in the midst of the climatic turmoil of the glacial cycles, a primate species in Africa learned a new trick: the use of fire. This species, destined to become humankind, began to derive energy from the controlled combustion of wood, peat and other detrital carbon left over from the cycling of the carbon-based biosphere all around it.

The ability to use fire would come to give its discoverers a unique evolutionary advantage: energy no longer had to be used as it was gathered or stored within the body of the gatherer. It could be stockpiled, concentrated and used as a transformative agent.

The full potential of this discovery was not realised until an 11,000-year period of relative warmth and calm in the glacial climate cycles (the Holocene), when humankind developed agriculture and started to form towns and cities, supporting specialisation. New economic, social and cultural modes of organisation became possible – all supported by technologies dependent on concentrated energy from the combustion of detrital carbon.

Astonishingly quickly, we are now confronted by finite-Earth vulnerabilities.

Changes were further accelerated by another critical discovery: energy could be derived not only from the carbon in wood but also from a much older source, the huge reserves of fossilised carbon laid down hundreds of millions of years earlier as coal, oil and gas. This ancient detrital carbon provided much more concentrated energy than wood, catalysing yet further forms of organisation which rapidly flowered into industry and advanced technology.

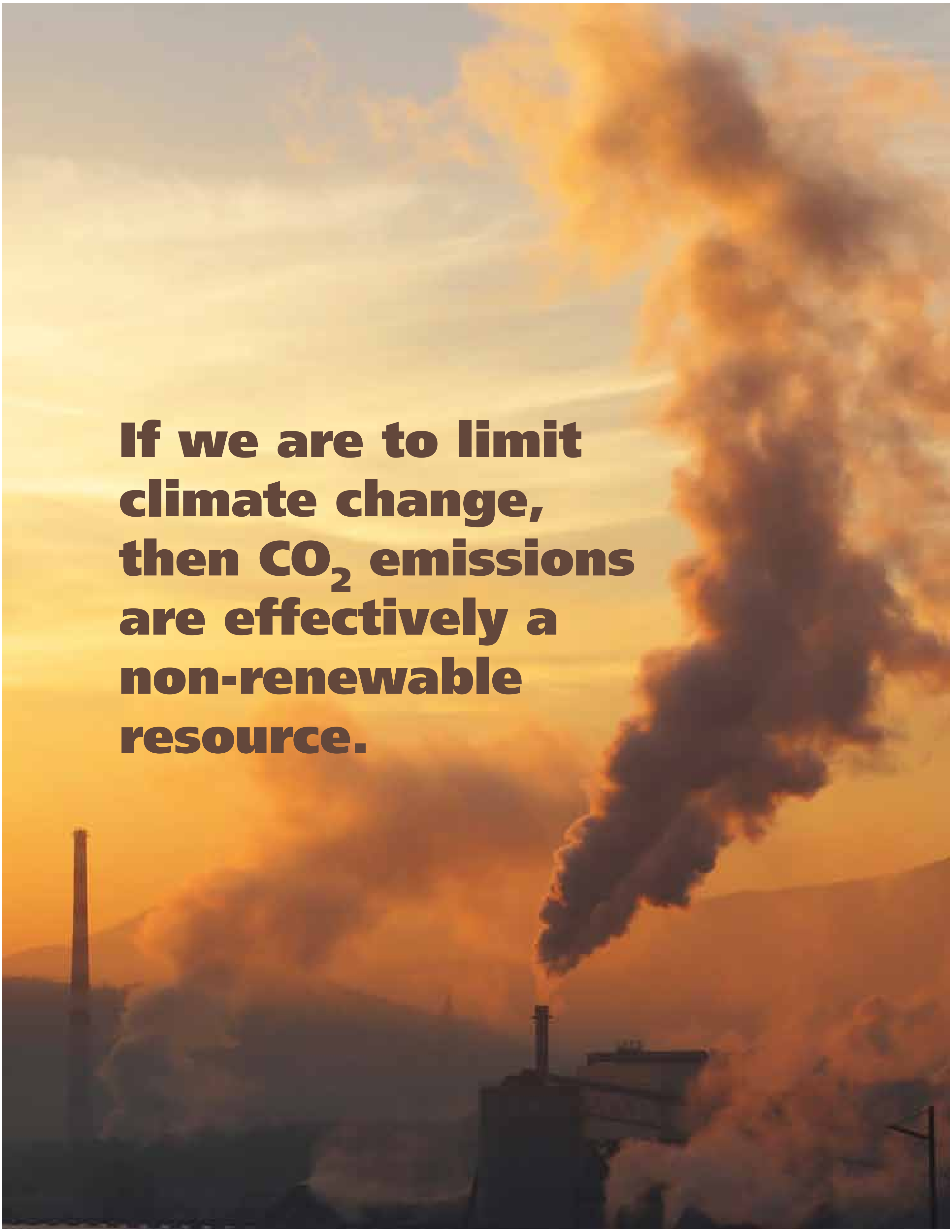
By exploiting this exogenous energy, the human species has come to dominate its planet. Its numbers have swelled to billions, its agriculture has transformed ecosystems, and its appetite for natural resources, including fossil fuels, has become insatiable. Human activities are now at such a scale that they significantly modify the climate, ecosystems and the Earth's great natural cycles of carbon, nutrients, energy and water, signalling the transition from the Holocene to the Anthropocene*.

At this time – the peak of human supremacy over its planet – the dependence of humanity on fossil fuels suddenly exposes a pair of vulnerabilities. First, the supply of natural resources is limited: among the fossil fuels, oil and gas are the most vulnerable.

Second, the planet has a limited capacity to metabolise the waste products from human activities without suffering damage – a major threat being climate change induced by the build-up in the atmosphere of CO_2 from fossil-fuel burning and land clearing. These two "finite-Earth" vulnerabilities respectively impose constraints on the inputs to and the outputs from human activities. Humans can consume a limited amount of natural resources and produce a limited amount of waste.

Peak oil

A widely used approach for assessing the first vulnerability – resource limitation – is the "Hub-



Credit: Istockphoto

bert curve". In 1956, the American geoscientist M. King Hubbert predicted that oil extraction in the US would peak in the early 1970s and then begin to decline.

At the time, not many geologists believed Hubbert, preferring to think of oil as a resource so great that it would last into some distant future. But Hubbert was proved correct, and his theory is now widely applied to predict reserves of non-renewable resources such as oil, gas and coal in specified areas or for the planet as a whole.

The basic idea, of which there are many variants, is that the extraction rate of a non-renewable resource follows a roughly bell-shaped curve. Extraction starts slowly as the resource is discovered, accelerates to a peak as exploitation of the resource increases, and then declines as the resource is depleted and further discovery and extraction become progressively more difficult. This means that the point at which half of the total resource is consumed coincides approximately with the point at which production is greatest.

Estimates of the Earth's fossil fuel resources vary widely. In 2008, the World Energy Outlook of the International Energy Agency put the ultimately recoverable resource for oil at about 410 Gigatonnes (GtC, one billion tonnes of carbon), including production to date (130 GtC), proven reserves (140 GtC) and estimated unproven and undiscovered reserves (140 GtC). For conventional gas, the ultimately recoverable resource is estimated as about 217 GtC, of which 28 GtC has been used. The ultimately recoverable resource for coal is much larger, probably over 1000 GtC, including 165 GtC of past production, 620 GtC of proven reserves and a conservative estimate of undiscovered reserves.

These conventional fossil fuel resources are supplemented by a large (though very uncertain) reserve of unconventional resources, including shale oils, tar sands and methane hydrates, which collectively may contain over 1000 GtC. Hence the world probably has a total fossil-fuel resource of over 2500 GtC, of which about 320 GtC have been used. Of the three major conventional resources (coal, oil and gas), oil is the one for which peak production is being reached first.

It would seem from these figures that the world has a large endowment of fossil fuels, enough to last for centuries. However, the second finite-Earth vulnerability, the limit on output, imposes another critical constraint.

Peak warming above preindustrial temperatures would be limited to 2°C if cumulative CO_2 emissions are kept to 1000 GtC.

Peak CO_2

The problem of avoiding dangerous climate change has long been framed as one of stabilising CO_2 and other greenhouse gas concentrations at particular levels such as 550, 450 or even 350 parts per million (ppm) CO_2 equivalent (a concentration measure including CO_2 and other anthropogenic greenhouse gases according to their contributions to global warming). However, several recent papers, including two in *Nature* (Allen et al. 2009, doi:10.1038/nature08019; Meinshausen et al. 2009, doi:10.1038/nature08017) have proposed a different and in many ways preferable view, in which the mitigation challenge is framed as that of putting a cap on total cumulative CO_2 emissions since the start of the industrial revolution. This means that if humankind is to limit climate change, then CO_2 emissions are effectively a non-renewable resource. A small long-term continuing emission may possible in the far future, perhaps 10 percent or less of current emissions, but this is so tiny that a cap on cumulative CO_2 emissions provides a robust guide to the requirements for avoiding dangerous climate change.

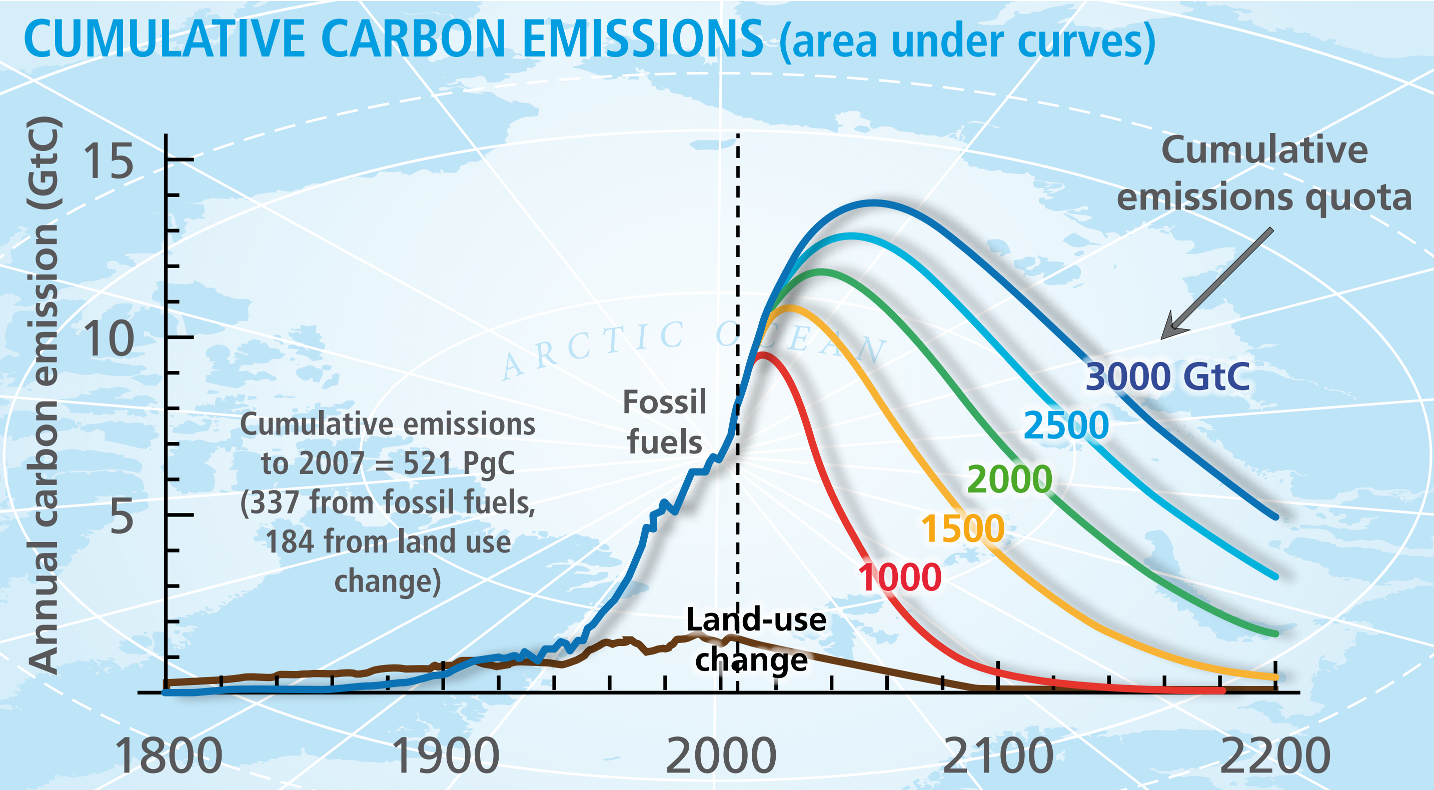
What is the "safe" quota for cumulative CO_2 emissions? Myles Allen from the University of Oxford and colleagues used several models to estimate that the peak warming above preindustrial temperatures would be limited to 2°C with a 50 percent probability of success if cumulative CO_2 emissions, which we will call Q, are capped at 1000 GtC (a trillion tonnes of carbon). Larger caps, Q = 1500 GtC and Q = 2000 GtC, would keep peak warming below about 2.6 and 3.2°C, respectively, likewise with a 50 percent probability of success.

The capped quota Q is the total cumulative CO_2 emission since the start of the Industrial Revolution (around 1750) to the far future. Hence, CO_2 emissions – like fossil fuels themselves – are a non-renewable resource.

A temperature rise of 2°C is often identified as the point at which the risk of "dangerous" climate change becomes significant (a concept necessarily involving a value judgement). Therefore, Q = 1000 GtC is the cap on CO_2 emissions required to give a 50 percent probability of avoiding "dangerous" climate change.

The 50 percent probability caveat is very important because there are great uncertainties in the prediction of future climate change in response to a given greenhouse gas emission trajectory. These arise from the difficulty in quantifying the reinforcing feedbacks in the Earth system associated (for example) with decreasing snow and ice cover, release of additional greenhouse gases from natural pools which are vulnerable under climate change (such as the carbon presently locked in permafrost), and a decrease in the fraction of CO_2 taken up by land and ocean carbon sinks. These sinks now absorb over 50 percent of all CO_2 emitted by human activities, but will absorb less in future if emissions continue to grow rapidly.

The uncertainties imply that if we want a higher probability of staying below a nominated peak



Past and future cumulative carbon emissions (area under curves) including emissions trajectories based on setting cumulative human emissions quotas of between 1000 and 3000 tons of carbon for combined emissions from fossil fuels and land use change.

warming, then the cap *Q* must be lower. For example, to stay below 2ºC peak warming with 70 percent rather than 50 percent probability, *Q* must be 800 GtC rather than 1000 GtC.

Avoiding catastrophe

Cumulative CO_2 emissions to date are about 520 GtC (320 from fossil fuels and 200 from land-use change). So, we've used up more than half of the 1000 GtC allowance. The halfway mark (a cumulative emission of 500 GtC) was passed around 2006. In this sense, the world has just passed "peak CO_2" if it is to avoid dangerous climate change. The halfway point in use of the global CO_2 emission quota *Q* also corresponds approximately with the point at which emissions must peak and thereafter decline, as in the red curve in the figure.

There is an important difference between peak CO_2 and peak oil. Non-renewable natural resources such as oil and coal will run out, imposing a hard constraint on their use, whereas the cap *Q* associated with peak CO_2 is the result of a value judgement by humankind about the degree of climate protection that it wishes to give to the global climate commons. If this value judgment is made differently – by changing either the maximum warming to be allowed or the risk level that is tolerated – then a different cap *Q* will result, as in the example trajectories in the figure. Unlike the limit on the use of a finite resource, which is inexorable, the cap *Q* must be decided with a long lead time because technical, institutional and cultural inertias prevent emissions trajectories from changing rapidly.

From the time that our distant forebears discovered fire until a few decades ago, the finiteness of our planet was not a consideration. Astonishingly quickly, we are now confronted by finite-Earth vulnerabilities arising from both the inputs to and the outputs from human activities. Of the two, the output vulnerability is the more acute. We have reached peak CO_2 – a cumulative emission of 500 GtC – before reaching peak oil, and long before exhausting half of the total fossil-fuel reserve of 2500 GtC or more. To allow the input limit to determine future fossil-fuel consumption is to invite climate catastrophe. ■

The 50 percent probability caveat is important because there are great uncertainties in predicting future climate change.

DR MIKE RAUPACH is co-chair of the Global Carbon Project, an Earth System Science Partnership (ESSP) project, and leads the Continental Biogeochemical Cycles Research Team at CSIRO Marine and Atmospheric Research, Canberra, Australia. IGBP is one of the four international programmes that comprise the ESSP.

*Anthropocene: a term first coined by Nobel laureate Paul Crutzen. Crutzen first used the term in print in IGBP's newsletter (No. 41, 2000).

CLOSING THE GLOBAL BUDGET FOR CO_2

Accurate global knowledge of where carbon is coming from and where it is going is essential to put in place international emissions reductions strategies. **Corinne Le Quéré** explains how the Global Carbon Project is contributing.

Carbon dioxide (CO_2) has been increasing in the atmosphere since the 18th century as a side effect of industrialisation. At first, the main culprit was large-scale deforestation for agricultural conversion. During the 20th century, energy from fossil fuels became widely used and now accounts for over 80 percent of the global CO_2 emissions. All together, 500-550 gigatonnes of carbon (GtC) in the form of CO_2 will have been emitted to the atmosphere before 2010. Yet, the increase of CO_2 in the atmosphere is less than half of the CO_2 emitted. Can we account for the remaining CO_2?

The available scientific knowledge tells us that the two large carbon reservoirs – the terrestrial biosphere and the oceans – have taken up the excess CO_2 in approximately equal proportions. However these CO_2 "sinks" are not fixed, in fact they are highly variable and respond to elevated atmospheric CO_2 levels and changes in the climate. To account fully for all the CO_2 emitted, we need to know the size of the land and ocean CO_2 sinks and their evolution in time. And we need to know this with an accuracy that is higher than the uncertainty in CO_2 emissions themselves. Full accounting of CO_2 emissions is a necessity if we are to monitor the transition from a CO_2-intensive to a low CO_2 economy. Unaccounted CO_2 emissions open the door to all kinds of abuses, from inaccurate accounting and declaration of countries' emissions to misleading demands for carbon credits associated with Clean Development Mechanisms and geoengineering options.

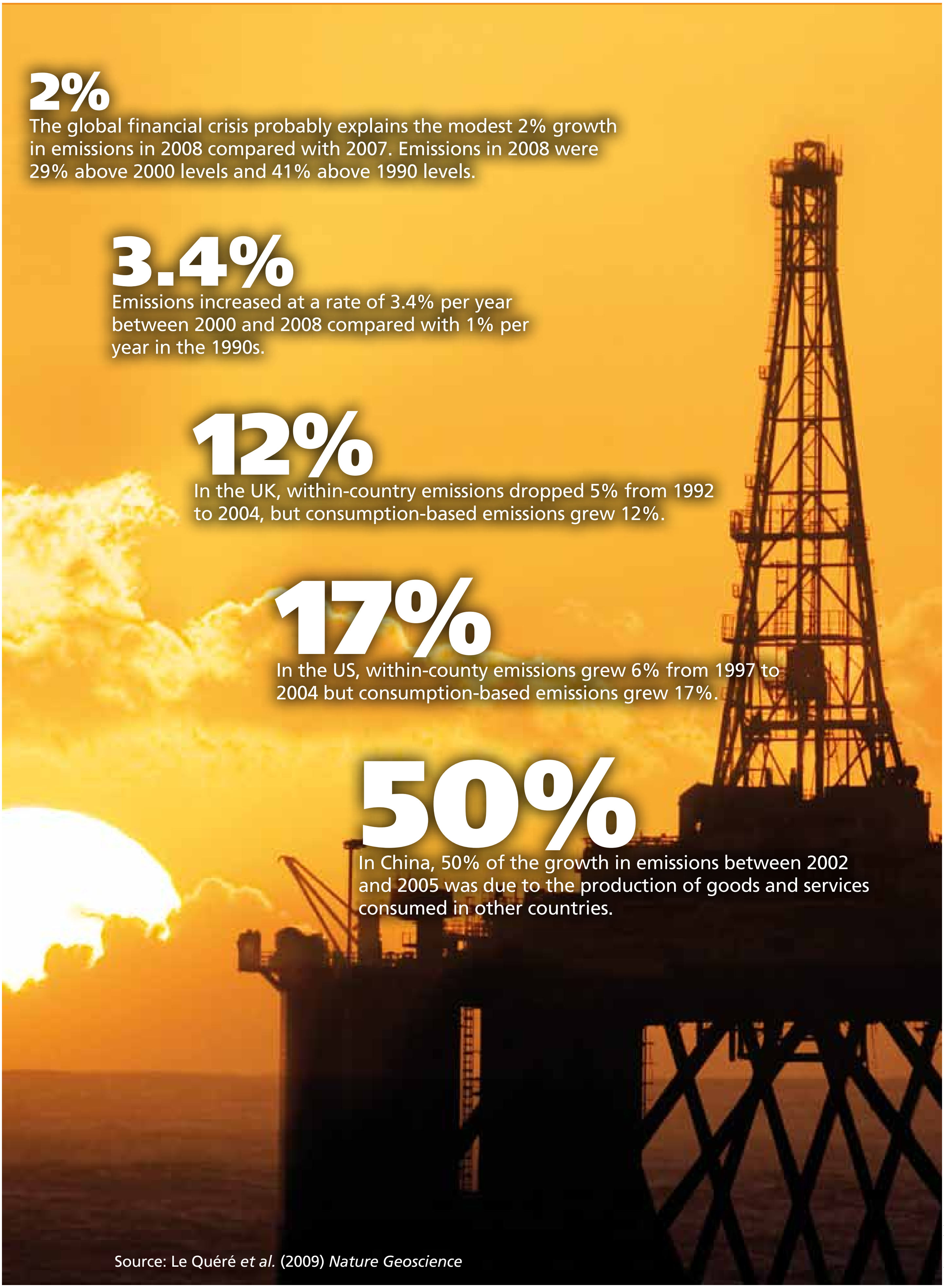
In the past decade, CO_2 emissions increased at a rate of 3.4% per year.

Can we quantify the global CO_2 sinks to such accuracy? To answer this question, we (Le Quéré *et al.* 2009) have put together a global CO_2 budget of all the major sources and sinks of CO_2 for every year from 1959 to 2008 (Figure 1). The aim is to provide information on the year-to-year changes in all aspects of the global CO_2 budget, and to identify the drivers of variability and trends. We used economic data to estimate CO_2 emissions from fossil-fuel combustion and land-use change. Atmospheric CO_2 was measured directly from a network of around 100 stations. We quantified the evolution of the land and ocean CO_2 sinks with the help of models. All models included key processes like plant productivity and respiration on land and circulation, chemical reactions and biological productivity in the ocean. All models were forced by increasing atmospheric CO_2 and the meteorological conditions corresponding to the time period of study. To minimise the errors, we used the mean of all models and estimated error using model spread.

Missing pieces

What were we looking for? The study compared estimated global CO_2 emissions from fossil-fuel use and land-use change with the annual sum of our best estimate of CO_2 increase in the atmosphere, ocean and land during this period (Figure 2). Of course, in theory the undulations of the two lines on the graph should be identical, but they are not: emissions grew steadily but there is considerable annual variability in the estimated CO_2 stored in the atmosphere, ocean and land. So current knowledge does not account for all emitted CO_2.

Known problems in the CO_2 budget explain most of the mismatch. For instance, in the 1970s, it seems there was more additional CO_2 in the system than emissions indicate. We know that La Niña-like conditions led to unusual cool, wet conditions pre-



2%

The global financial crisis probably explains the modest 2% growth in emissions in 2008 compared with 2007. Emissions in 2008 were 29% above 2000 levels and 41% above 1990 levels.

3.4%

Emissions increased at a rate of 3.4% per year between 2000 and 2008 compared with 1% per year in the 1990s.

12%

In the UK, within-country emissions dropped 5% from 1992 to 2004, but consumption-based emissions grew 12%.

17%

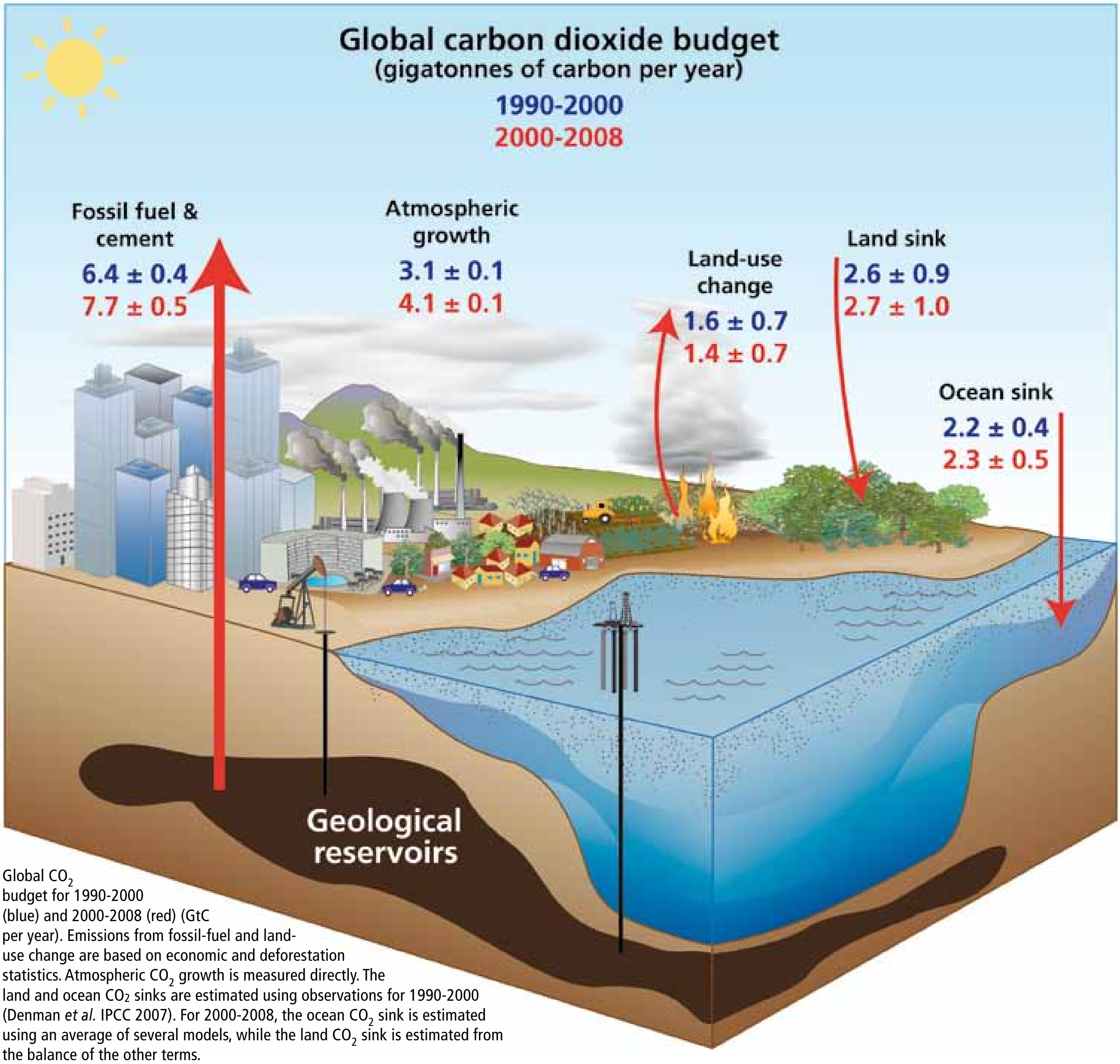
In the US, within-county emissions grew 6% from 1997 to 2004 but consumption-based emissions grew 17%.

50%

In China, 50% of the growth in emissions between 2002 and 2005 was due to the production of goods and services consumed in other countries.

Source: Le Quéré *et al.* (2009) *Nature Geoscience*

Credit: Istockphoto



Global CO_2 budget for 1990-2000 (blue) and 2000-2008 (red) (GtC per year). Emissions from fossil-fuel and land-use change are based on economic and deforestation statistics. Atmospheric CO_2 growth is measured directly. The land and ocean CO_2 sinks are estimated using observations for 1990-2000 (Denman *et al.* IPCC 2007). For 2000-2008, the ocean CO_2 sink is estimated using an average of several models, while the land CO_2 sink is estimated from the balance of the other terms.

vailing in the tropics throughout the 1970s causing more carbon to move to the land sink. The models overestimated the land-CO_2 uptake in response to these conditions.

Similarly, the massive Mount Pinatubo volcanic eruption in 1991, which affected climate globally by injecting large volumes of small particles into the upper atmosphere, helps explain the missing CO_2 in the early 1990s. The land models did not account for the increase in available light in the vegetation canopy from enhanced diffusion during and after the eruption.

Excess CO_2 in the late 1990s could in part be a signature of political incentives to clear land in Indonesia.

Finally, the excess CO_2 of the late 1990s appears to be partly a signature of political incentives to clear land in Indonesia that took advantage of the ongoing drought conditions.

Weakening sinks

One interesting result coming out of this analysis was that the trends in accounted CO_2 matched well the trends in emitted CO_2 – both rising at the same rate. This suggests that the processes represented in the models, such as the timescale of penetration of CO_2 in the ocean and the turnover time of soil carbon, are correct to a first order. We can use information on the trends to keep track of the partitioning of the emitted CO_2 between the atmosphere and the sinks. In particular, the fraction of the total CO_2 emissions that remained in the atmosphere – the airborne fraction – is a good indicator of the capacity of the land and ocean sinks to absorb excess CO_2 from the atmosphere. If the sinks weaken, more CO_2 will remain in the atmosphere and amplify global warming.

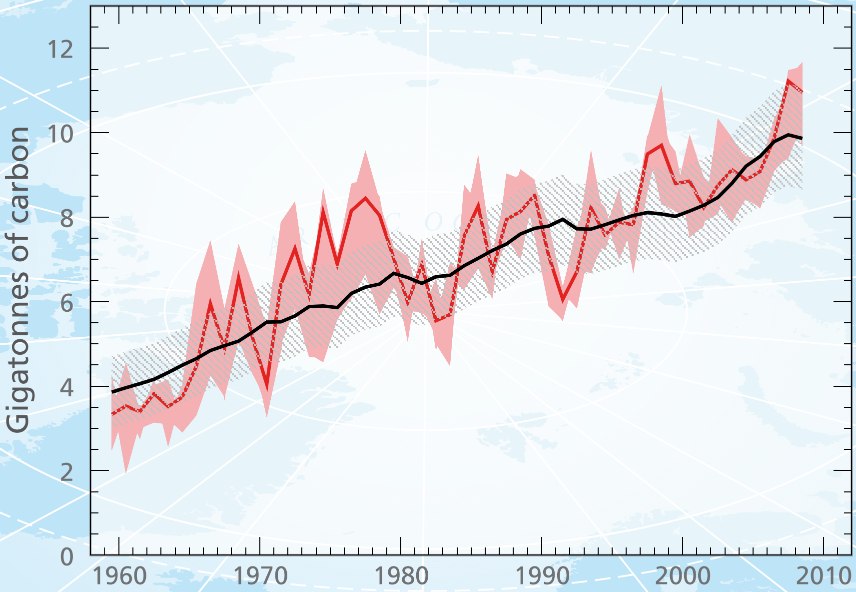
Our analysis of the trend in airborne fraction from this global CO_2 budget shows a likely positive trend of 0.3 percent per year, with a 90 percent probability the trend is above background variability and additional uncertainty due to poorly quantified land-use CO_2 emissions. The models reproduce such a trend and suggest it is a response of the land and ocean sinks to climate variability and climate change for the past 50 years. If the model results are correct in how they represent the processes that reproduced past trends, this supports the existence of a positive feedback between climate and the carbon cycle that was predicted by many carbon-cycle models.

The range of model results is representative of the uncertainty in the known processes. The range of results is smaller than the uncertainty in emissions, which supports the possibility that full accounting of emitted CO_2 is possible, even with existing models. However, to reach such a state requires major improvements in models' year-to-year estimation of CO_2 sinks.

The land models could be improved right away by including the known missing processes. The land and ocean models could also be improved further if the mismatch with observations can be constrained not only globally, but also spatially. Regional information is available from direct measurements in the ocean, and from inverse methods that provide information on the regional variability in the CO_2 fluxes.

We could achieve further improvements if the sinks could be quantified directly from observations. For the ocean, this may be possible with increased data coverage and improved analysis tools. There is little prospect of estimating the land CO_2 sink directly, and thus it will always have to rely on models. Model validation in this context becomes crucial as it ensures the quality of the model estimates.

CO_2 EMISSIONS



Black line: annual cumulative CO_2 emissions from human activities (fossil-fuel combustion, cement production and land-use change). Red line: accounted CO_2 (the sum of the atmospheric CO_2 growth, and the land and ocean CO_2 sinks. Some differences between the black and red curves are due to known problems in the CO_2 budget, particularly associated with the response of land plants to climate variability.

Economic slump

In the past decade, CO_2 emissions increased at a rate of three percent per year. The emissions are projected to decrease in 2009 in response to the global economic downturn. However this decrease should only bring the global emissions down to their 2007 levels. The key to decreasing global emissions in the long term is to decouple energy use from wealth. With the large reorganisation of the world's energy system that is required to stabilise CO_2 in the atmosphere, the global change in CO_2 emissions will be closely scrutinised in the future. There would be enormous benefits to society if the world's scientific community pulls its expertise together to provide information to account for all the CO_2 emitted to the atmosphere. This could assist a peaceful transition to a different economy, but also provide an early warning of how the natural carbon cycle responds to CO_2, climate and other environmental changes.

Between 1959 and 2008, 43% of each year's CO_2 emissions remained in the atmosphere.

PROFESSOR CORINNE LE QUÉRÉ is co-chair of the Global Carbon Project and a researcher at the British Antarctic Survey and the University of East Anglia, UK. The Global Carbon Project is an IGBP joint project with DIVERSITAS, the International Human Dimensions Programme and the World Climate Research Programme.
www.globalcarbonproject.org/

MORE INFORMATION

Le Quéré C *et al.* (2009) Trends in the sources and sinks of carbon dioxide. *Nature Geoscience* doi:10.1038/ngeo689.

Where sinking land meets rising water

Photo credit: U.S. Geological Survey

Five hundred million people living on the world's deltas now face the twin threats of subsidence and rising sea levels. **Christina Reed** reports from the edge.

Hidden along the edge of a cornfield and behind a three-metre-tall thicket of cattails and tubular stalks of a plant called tules, the telltale signs of a crawdad feast are scattered over a wooden plank that stretches across a dark pond. A thin layer of chartreuse-coloured milfoil blankets part of the marsh. The shading that the vegetation provides has a dramatic effect on the pond's temperature. Despite the Californian summer heat, the shallow water (0.3m) is cool to the touch. A family of otters has found this wetland, situated on an island in the Sacramento-San Joaquin River Delta, a perfect spot for lunchtime meals.

Whereas most deltas around the world are coastal features, California's largest delta is found far inland, where the San Joaquin and Sacramento Rivers merge and thread together into several distributaries that eventually lead to the San Francisco Bay. Deltas are the connection between river drainage basins and the world's oceans. They are inherently influenced by both of these physical domains as well as by the 500 million people who live in these highly productive, ecologically rich systems, according to a recent report from IGBP's Land-Ocean Interactions in the Coastal Zone project (LOICZ). Deltas are one of LOICZ's top priorities.

Deltas are dangerous, though highly sought after, places to live.

"We are developing plans to marshal our respective scientific communities to work together and better understand the scale and function of deltas," write three leading academics in the report's prologue, James Syvitski, the executive director of the Community Surface Dynamics Modeling System (CSDMS), LOICZ executive officer Hartwig Kremer and Janos Bogardi, executive officer of an IGBP joint project, the Global Water System Project (GWSP).

For more than a century, farmers in the Sacramento-San Joaquin River Delta have been draining peat soils on the delta's islands to grow crops that prefer dry roots, such as corn. Exposing the soils to air converts the peat into a giant buffet for aerobic microbes that rapidly start decomposing the organics. Wind and rain further erode the old peat. As a result, much of the land along the delta now sits six metres below sea level. Over the last 150 years, the delta in some parts has sunk two to five centimetres a year. A grid of levees keeps the rivers from flooding the land. But as the land continues to sink the pressure on the levees increases, and breaks in the system lead to floods. The most recent case of failure occurred on 3 June 2004, on a stretch of the levee where the farmland on the opposite side of the levee wall was three metres lower than the river's surface.

The wetland the otters found is part of a pilot project that scientists with the US Geological Survey started in the in the early 1990s with the intent of reducing the rate of subsidence. The preliminary study was designed to assess the use of various wetland types to mitigate subsidence of organic substrates in the delta.

"This is based on the idea that anaerobic decomposition is slower than aerobic decomposition, so decomposition, or loss of the underlying organic substrates, would be slower in wetlands than in drained soils," says biogeochemist Robin Miller who has led the USGS research on the project for the last 12 years. The experimental wetlands are located on two seven-acre test plots on Twitchell Island, which is about 40 miles south of Sacramento. Between 1997 and 2005 the wetlands gained more than 25 cm in elevation. "The rates of accumulation are coming as a surprise to everyone – including ourselves," Miller says.

Carbon trap

But that's not all. "We are seeing, in addition to subsidence reversal, huge net greenhouse gas benefits," says Roger Fujii, Bay-Delta programme chief for the USGS California Water Science Center. During their experiment they discovered that the new peat soils were storing much of the carbon that the plants were taking out of the atmosphere during their growing phase. "We didn't realise you could store so much carbon so quickly," Miller says.

The reason, she explains, is California's long growing season. "I don't think you could do this in Minnesota," she adds. The winters there are too long. "Our plants start growing in February and don't die until November; they are taking up carbon dioxide for all but two months of the year."

When they do die and start forming fresh organic peat soils, the slow decomposition, Miller estimates, produces less than five percent methane – another form of carbon and also an important greenhouse gas. In other words, an estimated 95 percent of the carbon that the plants take up during their growing phase is stored each year. But the funding to accurately measure methane and other greenhouse gases released during the decomposition phase and test what the scientists are now calling "carbon farming" on a larger scale is currently on hold.

The fresh water behind the levees is delivered to 23 million Californians.

In July 2008, the California Department of Water Resources awarded USGS and UC Davis a three-year $12.3 million research grant to "take the concept of carbon-capture farming to full scale in a scientifically and environmentally sound way". But state budget cuts this year have left the project in limbo. "There is no funding for the current wetland, or for the larger wetland that is supposed to be established on Twitchell," Miller says. The previous annual costs to support the pilot project's research in the wetlands and surrounding drained fields had ranged from about $0.4-1 million per year over 11 years, from 1997 to 2008.

If peat soils drained of water and eroded through exposure to wind and rain can grow back in California, and trap carbon in the process with minimum release of additional greenhouse gases, then the restoration of marshes in the area could potentially relieve

Photo credit: U.S. Geological Survey

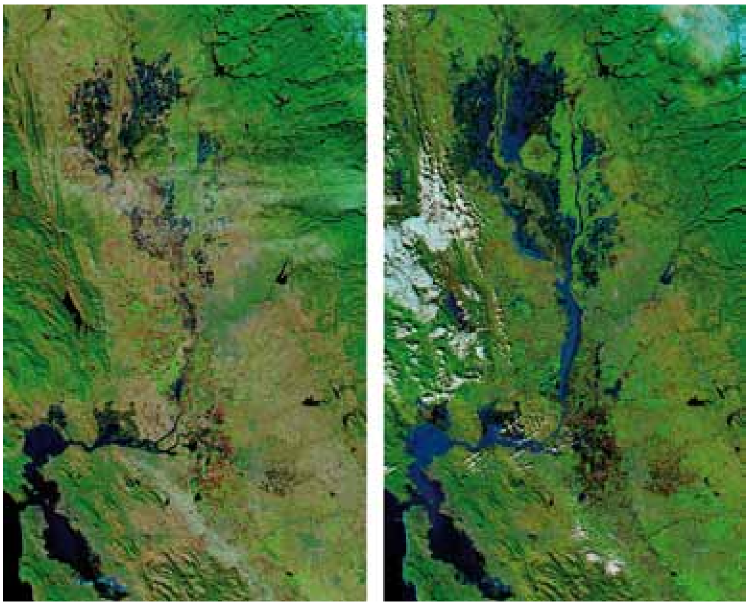
the stress on the levee system as well as combat climate change. Such a solution, the scientists hope, may even be economically beneficial to local farmers.

Sinking fast

In deltas around the world, the land is sinking faster than sea level is rising. For the most part the reason for the sinking is because dams and levees prevent the annual load of river sediment from reaching what are now lowland areas. The peat soils in California, however, are not starved of sediment, but rather starved of water. In other words, California's peat soils, while somewhat unique, give us good insights into the workings of a delta.

So how applicable are the insights gained from the California project to other deltas? It turns out that the draining of wetlands is common to other deltas too. As the LOICZ report mentions: "Draining wetlands can cause soil organic matter oxidation and increase subsidence rates far above geologic subsidence rates. There have been enhanced rates of subsidence in the Rhine and Sacramento deltas because of soil oxidation."

In the 20 September issue of *Nature Geoscience* the same editors of the LOICZ report, Irina Overeem and Syvitski, along with other colleagues at the University of Colorado in Boulder, published a survey of 33 deltas around the world. They concluded that globally most deltas are vulnerable to flooding as "a result of sediment compaction from the removal of oil, gas, and water from the delta's underlying sediments, the trapping of sediment in reservoirs upstream, and floodplain engineering in combination with rising global sea level". They did not include the Sacramento-San Joaquin River Delta or the Rhine Delta in their study. But they found that Italy's Po Delta, where people mined methane gas during the 1960s and early 1970s, had subsided 3.7 metres during the 20th century, with 81 percent of the subsidence attributed to the gas mining. Groundwater withdrawal from the Chao Phraya Delta in Thailand is causing the land to sink 50 to 150 mm per year.



NASA image courtesy the MODIS Rapid Response Team, Goddard Space Flight Center

This pair of images shows flooding in the Sacramento-San Joaquin Valley region inland of San Francisco Bay. The image on the left was captured on 10 December 2005, while the image on the right was captured on 4 January 2006, just days after the severe storms passed through.

In deltas around the world, the land is sinking faster than sea level is rising.

Nurturing organic soils is not a likely solution for these areas. In the Po Delta the levees are upwards of 12 to 15 metres above the lowlands, higher than the rooftops of the houses that have been developed on the agricultural land. The percentage of peat in the delta is minimal, roughly three to four percent, says Annamaria Correggiati of the Istituto di Scienze Marine-Consiglio Nazionale delle Ricerche Sede di Bologna. There is an experimental effort to reduce subsidence by pumping water back into the substrate during natural-gas capture, but this she says is "very experimental and very new". As for the Chao Phrya Delta, it was never peat. "Chao Phrya is all shrimp farms, and presently these are replacing the mangrove forests," Syvitski says.

Syvitski's team found 85 percent of the deltas they surveyed had experienced severe flooding during the past decade, "resulting in the temporary submergence of 260,000 km^2". They estimate that at the current projections for sea-level rise, the surface of delta land vulnerable to flooding could increase by 50 percent in the future. Of the deltas they surveyed they found that most are "sinking at rates many times faster than global sea level is rising".

In order of increasing risk they identified three categories of deltas: those that have reduced sediment accumulation that can no longer keep up with local sea-level rise (including Brahmani, Godavari, Indus, Mahanadi, Parana and Vistula); those that have reduced sediment accumulation plus accelerated compaction of their sediments, which combined are overwhelming the effects of global sea-level rise (including Ganges, Irrawaddy, Magdalena, Mekong, Mississippi, Niger and Tigris); and finally those with virtually no sediment accumulation and/or very high compaction (for example Chao Phraya, Colorado, Krishna, Nile, Pearl, Po, Rhone, Sao Francisco, Tone, Yangtze and Yellow).

Creaking levees

From the wetland on Twitchell Island, the levee looks like a long, flat hill. It is only by driving up on top of the levee that the expansive Sacramento River is visible on the other side. A sealion in middle of the river barks loudly on a buoy. Miller explains the growing strain on the levee system by comparing the weight of the water on the river side of the levee with the weight of the air on the lower, farmed side of the levee. “If I have a bucket of water in my hand it’s heavy. For every centimetre higher the water level rises or every foot lower the land sinks, that’s added water weight the levee has to hold,” she says. The difference in the height of the levee and the low-lying ground coupled by the weight of the water behind the levee is a universal risk among deltas. But Sacramento-San Joaquin River Delta has another risk factor that other deltas don’t usually have to worry about: earthquakes. “The worst case scenario is if this levee breaks during an earthquake and the water rushes across the farmlands and takes out the levee on the other side,” Miller says. Following the disaster that happened during Hurricane Katrina in New Orleans, she says these levees are now potentially the worst in the country. The fresh water behind the levees is delivered to 23 million Californians. “Should salt water flow back into the pumps it might take up to two years to flush out the salt water again,” she says. She is echoing the estimate the late Marc Reisner proposed in his 2003 article that was posthumously published, ‘A Dangerous Place: California's Unsettling Fate.’


Photo credit: U.S. Geological Survey

Robin Miller has been studying the Sacramento Delta for the past twelve years.

Danger zone

Deltas are indeed a dangerous, though highly sought after, place to live. As the LOICZ report explains, “Both the river and the ocean nourish the delta system with fluxes of water, sediment and nutrients. Consequently, deltas are highly productive, ecologically rich systems and have been attractive areas for settlement of humans from the earliest civilisations. Deltas are immensely important for food production and aquaculture.” In the *Nature Geoscience* survey, Syvitski and colleagues report that: “In 2007–08 alone, the following deltas experienced substantial flooding: Ganges, Mekong, Irrawaddy, Chao Phraya, Brahmani, Mahanadi, Krishna and Godavari, with more than 100,000 lives lost and more than a million habitants displaced.” Syvitski considers subsidence a considerable threat.

This is reflected also in the LOICZ report’s call for a “multidisciplinary, problem-driven approach with experts from the fields of engineering, ecology, geography and human dimensions,” to address the “urgent needs of our world deltas and their vulnerabilities, resilience and risks”.

They conclude that the technology envisioned for an integrated framework for delta research and management will incorporate “morphological models that predict natural delta dynamics as a function of changing processes, combined with GIS tools that help exploring socioeconomic scenarios. Risk mapping would then include a variety of parameters like risk of flooding due to river floods, risk associated with tsunamis and hurricanes, risk of accelerated subsidence, risk of habitat loss for threatened species”.

We didn’t realise you could store so much carbon so quickly.

CHRISTINA REED is a science writer.

MORE INFORMATION

Overeem I & Syvitski J P M (2009) Dynamics and vulnerability of delta systems. *LOICZ Reports & Studies* 35. GKSS Research Center, Geesthacht.

The CSDMS Integration Facility based in Boulder, Colorado, is a “virtual home for a diverse community of experts, presently from 22 countries and 135 institutions, who foster and promote the modelling of Earth-surface processes.”

The Global Water System Project, GWSP, is a joint project of the Earth System Science Partnership committed to analysing the effects of global change on the planet’s water system.

Climate services for all?

Climate services is an idea that has been floating around for some years. Has its time arrived? At the **World Climate Conference**, aid agencies, water resource managers and farmers certainly hoped so.

Hassan Mahmud, the quietly-spoken Bangladeshi Minister of State for Foreign Affairs, knows more than most about the risks posed by climate change.

At the Third World Climate Conference in Geneva he rattled off a stream of statistics that combine to make Bangladesh arguably the country most vulnerable to rapid environmental change. With a population of 150 million, Bangladesh has the highest population density in the world. On average, 1000 people cram each square kilometre.

The burgeoning population live on the world's largest delta. This low-lying land, squeezed between the Himalayas to the north and the Bay of Bengal to the south, makes severe hardship, largely caused by monsoon floods and typhoons, inevitable. Up to one third of land is under water for part of the year. The name Bangladesh – meaning Country of Bengal – is apt.

"Bangladesh is a country of disaster and natural calamity," Mahmud told the 2500-strong conference made up of the UN, scientists, government departments, funding bodies and aid agencies.

"With rising sea levels, saltwater intrusion in low-lying areas could cause a 40 percent reduction in grain production. Climate change is exacerbating the risk of disaster."

Schemes that transfer risk from poor farmers to global financial markets are viable.

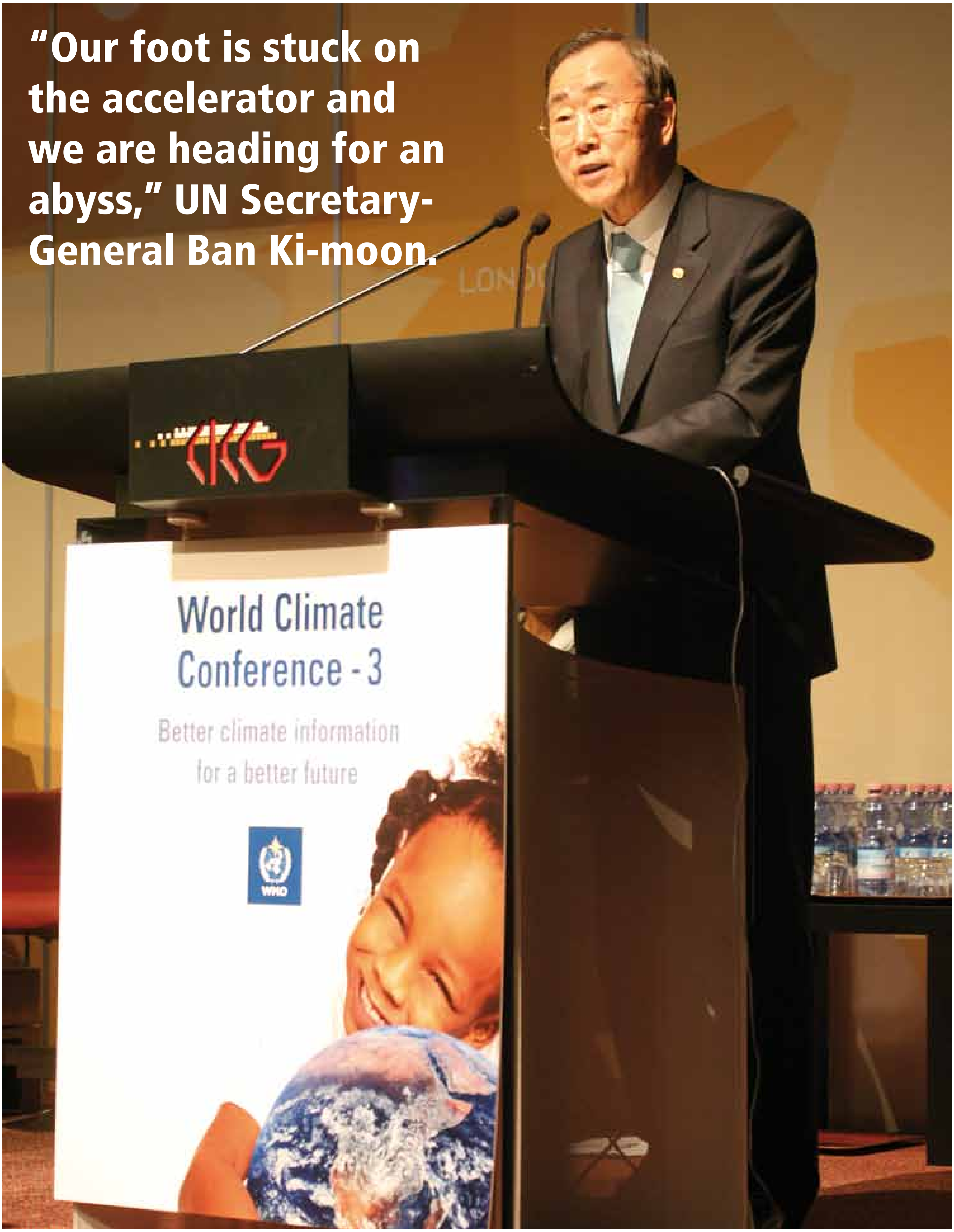
Mahmud was not there to complain about his country's lot. Bangladesh is working hard to adapt, and climate research is helping. The minister discussed an effective typhoon warning system now in place, based on 116 community radio stations. He emphasised the need to work across scales to develop effective adaptation measures. Research centred on regional and global scales needs to be interpreted at the local scale of towns and cities if it is to be of any use. This point was to come up repeatedly throughout the conference, the third of its kind in 30 years.

The first World Climate Conference, in 1979, led to the World Climate Programme (which includes the World Climate Research Programme), and later to the Nobel prize-winning Intergovernmental Panel on Climate Change (IPCC) and IGBP. The second, in 1990, called on governments to establish a climate convention, adding momentum to international efforts that resulted in the UN Framework Convention on Climate Change in 1992. It also led to the establishment of the Global Climate Observing System.

But, while the IPCC has helped translate the work of WCRP, IGBP and many other research programmes into user-friendly assessments primarily for national and international policymakers, there has been significantly less progress in translating the research into products useful to water management experts, farmers, the health sector, the insurance industry, aid agencies and the like, particularly on shorter timescales and at local and regional levels.

Out of control

The third World Climate Conference, organised by the UN's World Meteorological Organization, aimed to rectify this deficiency. The conference was called to create what is being called a "global framework for climate services". Secretary-General Ban Ki-moon, who had just returned from the high Arctic where he had met polar researchers on the Svalbard archipelago, was in no mood for procrastination. "I have seen the sober reality of climate change with my own eyes," he said. "Our foot is stuck on the



"Our foot is stuck on the accelerator and we are heading for an abyss," UN Secretary-General Ban Ki-moon.

Photo courtesy of the World Meteorological Organization accelerator and we are heading for an abyss." Delegates from over 150 nations promptly agreed the proposal.

The new climate service will provide information and predictions on the time and space scales needed by society. Major advances in the science over the last 30 years means reliable seasonal and decadal climate predictions are no longer a pipe dream but a realistic proposition. This will allow, for the first time, key sectors to adapt and prepare vulnerable areas.

It looks likely the new framework will have four components: observation and modelling; research and prediction; a climate services information system taking data and results from the first two; and finally, a front end to translate and interpret the information for the various sectors – governments, agriculture, water, health, energy, conservation, aid agencies. This will be the "User Interface Programme".

The third part, the climate services information system, will focus on what all the various sectors need and feed this information to the research programmes. The two-way flow of information allows it then to take data from the programmes and interpret it for particular industries or locations.

The first component – observation and modelling – is well established, according to Deliang Chen, executive director of the International Council for Science. But it is recognised they need bolstering. Indeed, one of the five key recommendations coming from the conference was stronger links between WCRP, IGBP and the other global-change programmes. There is a need for a full Earth-systems approach with more integration between international programmes. Scientists also called for greater access to the world's most powerful computers.

The architects of the new framework seek several outcomes. First, strengthened local, national, regional and global observational networks and information-management systems for climate.

Image courtesy Jacques Descloitres, MODIS Land Team

MODIS true-color image of the Ganges-Brahmaputra delta.

Climate services is an idea that has been gestating for some time.

Second, better climate modelling and prediction capabilities, achieved by focusing international research on seasonal-to-decadal timescales. Third, better provision for climate services nationally. This inevitably means many more discussions between researchers and the organisations that will use the service.

But this is not without its challenges. During the conference aid agencies and other sectors brought home the point again and again: the research community often shoves out masses of data onto loading docks and expects others to cart it off and make sense of it.

Cross roads

Madleen Helmer from the International Federation of Red Cross and Red Crescent Societies summed up her frustration. She explained how her team spent weeks poring over satellite data before abandoning the work

Children from a shanty town in the suburbs of Dhaka surrounded by highly polluted water.

Bangladesh is a country of disaster and natural calamity.

unable to find useful data.

"We need to go to where the knowledge is. And where this knowledge is, is not a traditional partner for the Red Cross and Red Crescent."

Walter Baethgen from the International Research Institute for Climate and Society reiterated the point. "If I break my leg playing football and need an X-ray, I don't want to be told my bone reflects 40 percent of the X-rays and absorbs 60 percent and that an anomaly has been noticed."

Helmer says seasonal forecasts, though, are what they need desperately. Plus a way of getting information to people who may live in a place that sees one bus a day.

"We want a permanent dialogue between the knowledge centres and those that can use that knowledge." The new service hopes to provide such a dialogue.

Trading in risk

Ulrich Hess from the UN's World Food Programme described new climate-related initiatives for farmers. He claimed the climate science community is "sitting on a treasure that will allow the global trading of risk".

New schemes designed to transfer the risk from poor farmers to global financial markets are proving viable. A pilot scheme, set up in India in 2003, is spreading throughout the world. So far, more than two million policies have been sold in India alone.

"We need good historical data, good real-time data and weather stations close to farmers."

The insurance industry particularly likes such schemes because they remove "moral hazard", its term for fraud.

"If there is a third party – a reliable weather station, for example – we have a guarantee that a claim is genuine."

The fact that the conference brought so many sectors together with the research community made it a valuable step forward in genuine engagement. The same points were often made day after day – emphasising the need for more dialogue.

US backing

The head of the US delegation, Dr Jane Lubchenko, said, "Imagine farmers able to determine what to plant and where, based on drought forecasts three to five years out. Imagine city planners and water resource managers able to ensure water for drinking, energy production, agriculture and many other uses. Imagine public health officials being ready for, or even able to avoid, outbreaks of malaria."

Lubchenko, who also heads the National Oceanic and Atmospheric Administration, added, "The concept of climate services is an idea that has been gestating for some time. Today marks the day that climate services was born."

For Mahmud and 150 million Bangladeshis the news comes not a moment too soon.

Written by OWEN GAFFNEY,

GETTING A HANDLE ON ECOSYSTEM SERVICES

Ecosystems provide society with valuable services such as food, clean water, fresh air and energy. They protect us from floods, droughts and disease, and give us healthy soils and cycle nutrients. The idea of ecosystem services is being adopted in some areas. But, says **Naomi Lubick**, is there an effective way of valuing these services?

Society needs a much clearer idea of the services ecosystems provide for us. Land-use change is perhaps the biggest human impact of all on terrestrial ecosystems. For this reason global environmental-change researchers interested in land use are no longer limiting their view to ecosystems alone. They are adding human systems into the mix, and calling it "land systems" – the coupled socio-environmental and terrestrial system that includes land use, land cover and ecosystems.

The results of this line of thinking are already attracting attention. In 2009, a collection of six related papers published in *Proceedings of the National Academy of Sciences* (*PNAS*) was awarded the Sustainability Science Award of the Ecological Society of America. The papers, co-authored by researchers associated with an IGBP joint project, the Global Land Programme (GLP), dealt with wide-ranging challenges from urban sprawl in the United States to improving the quality of animal feedstock in the French Alps and the vagaries of drought and livestock markets on land management in Australia. It turns out that some of the key factors governing ecosystem functioning were both unexpected and surprising.

According to Professor B L Turner II, the editor of the *PNAS* collection, the papers show "where land-change science is going". The environmental geographer, who recently moved to Arizona State University from Clark University, says the authors were "trying to demonstrate… that there's a series of large complex problems, integrated problems, in which the whole cannot be understood without the coupled pieces". But can one method assess the value of an ecosystem and predict how land-use change will devalue ecosystem services?

First step

The simple answer is no. Depending where on the planet you live, human land use and ecosystem change might lead to the intru-

Credit: Istockphoto

sion of seawater into groundwater on coastal agricultural lands as farmers pump more fresh water during droughts; severe and rapid soil erosion in clear-cut forests, whether in Brazil or Indonesia, with impacts on carbon dioxide in the atmosphere; loss of endemic species in fields turned to home lots in suburban United States; or forced migration because of rising sea levels.

All of these scenarios come back to ecosystem services and the perceived value of a landscape to humans and how they use it.

The growing importance of ecosystems services over the past decade was recognised by the Millennium Ecosystem Assessment (MEA) published in 2005, which played a seminal role in shifting attitudes toward modelling human impacts and land uses, says Alexander de Sherbinin, a senior research associate at CIESIN (Center for International Earth Science Information Network), at the Earth Institute at Columbia University in New York City. De Sherbinin says, "MEA was very important: its framework and approach to understanding ecosystems changed the perspective from 'we need to protect biodiversity' to 'look, there are all these services provided'."

Because of this sea change in thinking about ecosystems, de Sherbinin continues, "now everybody talks about ecosystems services" when addressing sustainability issues – no longer "protecting just flora and fauna".

Modelling the world

Valuing ecosystem services was a profound development, says Turner, but economists still struggle to put dollar values to services like wetlands water purification, the aesthetic beauty of a forest or carbon dioxide storage in peat to prevent climate change (though carbon is now easier to evaluate because of market trading). And while political ecology has come at these issues from the human side – considering ownership, politics and impacts on humans and by humans – land-change science adds humans to the landscape as another integral component, along with plants, animals, soil, water and more, Turner emphasises.

Valuing ecosystem services was a profound development.

Turner adds that it's not as simple as demonstrating that humans suffer once a service is degraded, "There's no correlation, at least in the short run, between the material well-being of society and deterioration of [ecosystem] services." And that means that land-use science must show the connections between an ecosystem and how it affects human outcomes.

"You want to ask the question: what are trade-offs between ecosystem services? That means you understand [that system]", Turner says. "The human element is so strong, it is already taking away value and structure of the system." He lists some of the myriad questions that need to be asked: What are the systems out there? How are they coupled? What does that mean for human consumption, social equality and other human issues?

Thinking small

In the French Alps, for example, where alpine pastures feed cattle over the summer, researchers find that the presence of certain plants with tender leaves and high nitrogen content make all the difference in weight increase for the livestock. Professor Sandra Díaz of the Universidad Nacional de Córdoba (Argentina) and her colleagues created a two-stage decision tree that let them test each plant species' traits weighed against variables such as soil type, climate, and other non-biological conditions, all in the service of providing feed for grazing, soil fertility, or other community-valued endpoints.

In the first steps, researchers test the effects on ecosystem properties of core drivers individually: non-biological factors like rain and elevation, traits that are distributed across the community and then averaged to get a weighted value, and particular species and their impacts on an ecosystem. The second stage takes the combined possible effects of these factors that are statistically significant and tests them together, looking for the best predictive model of what might happen, when, say, one species is removed from a foodweb.

"Using our method, we realised the most important factor in weight increase in livestock is the presence of certain plants with tender leaves and high nitrogen content," says Díaz, and to keep that particular service, a land manager in this alpine setting would have to make sure to keep plant species that fit the bill. But a landscape could be poised to give very different services – from birdwatching to carbon sequestration to water retention. Depending on the services people care about, the team's system could help determine which components of the ecosystem most strongly influence those services. Díaz and her colleagues are now working to apply the modelling tree to local ecosystems in Argentina, and she has heard that other researchers are interested in using it as far afield as Australia.

"Why is this an improvement?" Díaz asks. "Before, people were simply studying statistical relationships… between services and diversity with just a number of species. It didn't tell you much as to how [an ecosystem] was functioning or what you could do to preserve it."

She emphasises that the team's model is "completely useless if you don't know a minimum number of things about a system", from the influence of soil texture to the range and variety of species in a place. Modelling of all these components over different timescales can show changes in time or single snapshots, depending on the data available.

While the model (which received the Cozzarelli Prize in 2007 for "exceptional contributions to the scientific disciplines represented by the National Academy of Sciences", Class VI Applied Biological, Agricultural, and Environmental Sciences) was purely biological, Díaz says she is working on "trying to link it up with ecosystem services as defined not by scientists, but by the local stakeholders. The concept of ecosystem services is so rich, and so socially dependent, that we need to get into the details: different habitats, different peoples… it's really ecosystem specific."

"There are all these analytical issues we still haven't been able to solve," Turner notes, but Díaz and her colleagues' contribution is "one step on the biophysical side. The next step is to translate to human outcomes."

It's really, really hard to talk about climate change and land-use change separately.

Changing climate

One of the biggest challenges facing humans and their land-use choices is shifts in global climate, which are already intrinsically difficult to model. And this is where some researchers think these inclusive land-use models that integrate humans could be quite useful. "Climate change is sort of a matrix that sits over the whole thing," says Steve Carpenter of the University of Wisconsin-Madison, who has co-authored research with Díaz. "When we think about configuring landscapes, we have to think about a very long time horizon of directionally changing climate."

Some landscapes will be very vulnerable to climate change, while others will not. For example, in a region where evapotranspiration will increase, water stress will be greater for both people and other living organisms there. One solution would be to manage a landscape so that it absorbs water, "or create a water-bank in that area", Carpenter says.

Climate change also leads to a second big issue: the allocation of land to mitigate climate effects. "Carbon storage is a prime example there… but under many scenarios, future land storage [of carbon] is going to diminish," Carpenter points out, as forests disappear and soils degrade, for example.

"Nowadays, it's really, really hard to talk about climate change and land-use change separately," comments Díaz. "Both influence each other, [with] changes in climate triggered by land use, and the other way around." Ideally, she continues, her team's local model might lead to insights into which plants will have the right climate tolerance for a region. And if a key species disappears, "then you can anticipate [that and] start looking for another legume as close as possible to the one before with wider climate tolerance."

But Díaz emphasises that her team's model works at the local scale, from patches to landscapes, and it's difficult to scale up. Climate models, on the other hand, do best at large scales, and regional climate assessments are less certain.

Credit: Istockphoto

"Using our method, we realised the most important factor for weight increase in Alpine cattle is the presence of certain plants with tender leaves and a high nitrogen content."

Management troubles

"There's a notion out there that we'll be able to manage huge tracts of land for carbon, for water… for all sorts of things. My own take is more sceptical," comments de Sherbinin. He ticks off classic examples that have worked, such as the Catskills watershed that supplies water for New York City and China's afforestation efforts to prevent future devastating floods on the Yangtze River.

De Sherbinin also mentions California's steps to require developers to consider carbon sequestration before building, as buildings replace forest, peat or other ecosystems that lock away greenhouse gases. "It's a reality – they basically have to address this now, so it's not entirely pie-in-the-sky that these issues won't come forward," he says. But while "we have the tools… land isn't managed that way generally."

Díaz says that the emerging land-system discipline, sometimes referred to as "coupled human-environmental systems" or "coupled social ecological systems", is interdisciplinary, but researchers need to remember: there is "no distinction between the human and the environment, nor should there be". Díaz concludes: "Part of our failure to manage the land in a better way so far is a lack of realisation that we have to approach the system interdisciplinarily".

NAOMI LUBICK is a freelance science writer.

Everybody now talks about ecosystem services when addressing sustainability issues.

MORE INFORMATION

The Ecological Society of America granted the 2009 Sustainability Science Award to a special feature on land-change science, 'Evolution of urban sprawl', which appeared in the journal *Proceedings of the National Academy of Sciences,* 26 December 2007.

Turner B L II, Lambin E F, Reenberg A. Land Change Science Special Feature: The emergence of land change science for global environmental change and sustainability. *PNAS 2007 104:20666-20671; published online before print 19 December 2007, doi:10.1073/pnas.0704119104*

B.L. Turner II is on the scientific steering committee of the Global Land Project, co-sponsored by IGBP and the International Human Dimensions Programme.

GLOBAL IGBP CHANGE

International Geosphere-Biosphere Programme

Join the IGBP network

www.igbp.net

IGBP core projects

Analysis, Integration and Modelling of the Earth System (AIMES)

Global Ocean Ecosystem Dynamics (GLOBEC)

Global Land Project (GLP)

International Global Atmospheric Chemistry (IGAC)

Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS)

Integrated Marine Biogeochemistry and Ecosystem Research (IMBER)

Land-Ocean Interactions in the Coastal Zone (LOICZ)

Past Global Changes (PAGES)

Surface Ocean-Lower Atmosphere Study (SOLAS)

Synthesis, integration and exploration

Geoengineering

The role of changing nutrient loads in coastal zones and the open ocean in a high CO_2 world

Global nitrogen assessment and a future outlook

Earth-system resilience: Earth-system prediction

Earth-system impacts from changes in the cryosphere

Megacities and coastal zones

Global environmental change and sustainable development: the needs of least developed countries

The role of land cover and land use in modulating climate

Aerosols

Global environmental change joint projects

Global Carbon Project (GCP)

Global Environmental Change and Food Systems (GECAFS)

Global Water System Project (GWSP)

Global Environmental Change and Human Health (GECHH)

ICSU's global environmental change programmes

DIVERSITAS

International Geosphere-Biosphere Programme

International Human Dimensions Programme

World Climate Research Programme

And their Earth Systems Science Partnership

ICSU International Council for Science

IGBP is an ICSU global environmental-change programme.

IGBP focuses the international research community on the planet's key biogeochemical processes – the carbon, oxygen, nitrogen, water, phosphorus, and sulphur cycles. Our work includes understanding and predicting how these cycles are changing and the impact of human activities on them.