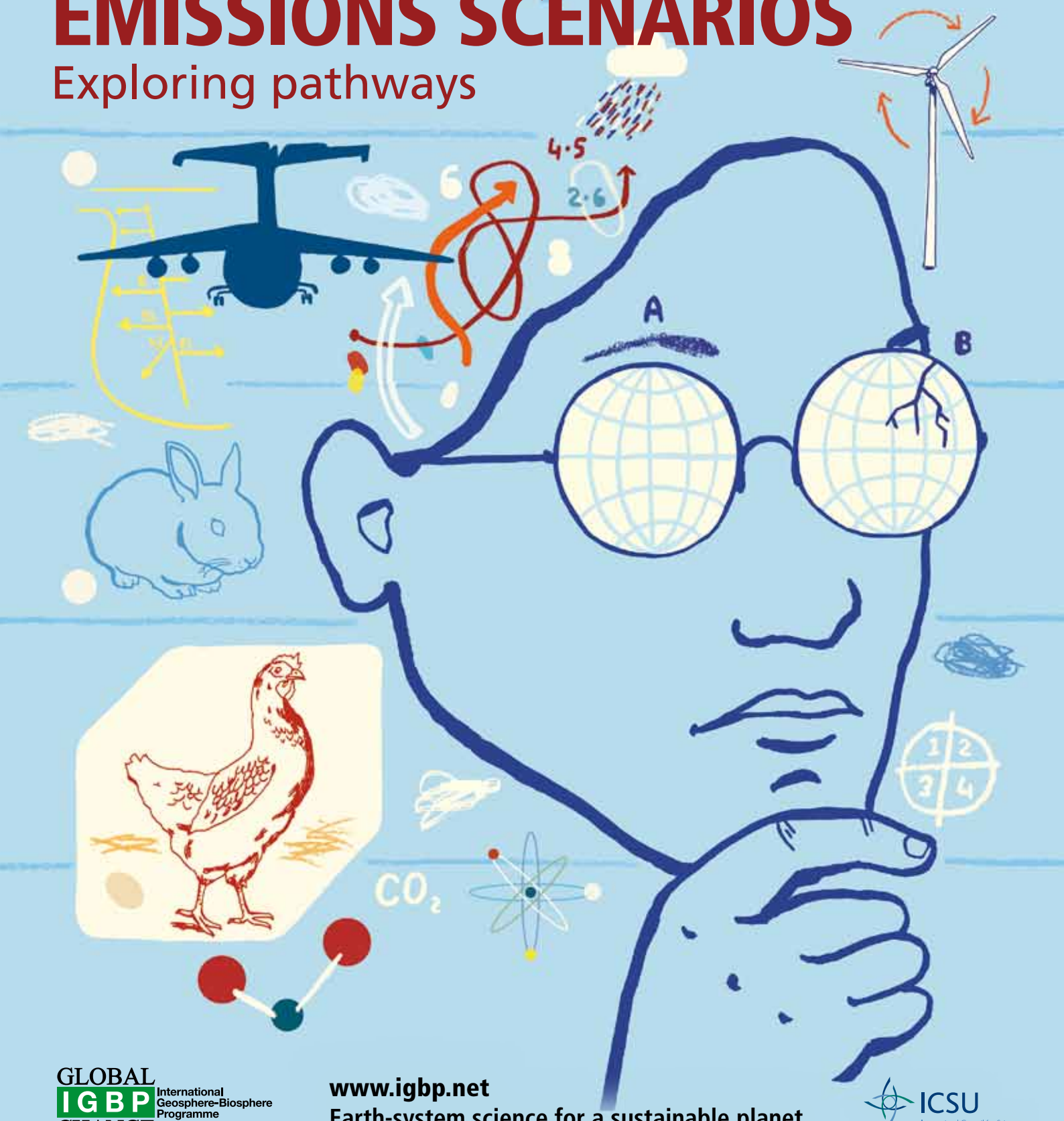
Global Change

International Geosphere-Biosphere Programme

Issue 75 ▮ June 2010

EMISSIONS SCENARIOS

Exploring pathways



GLOBAL CHANGE IGBP International Geosphere-Biosphere Programme

www.igbp.net

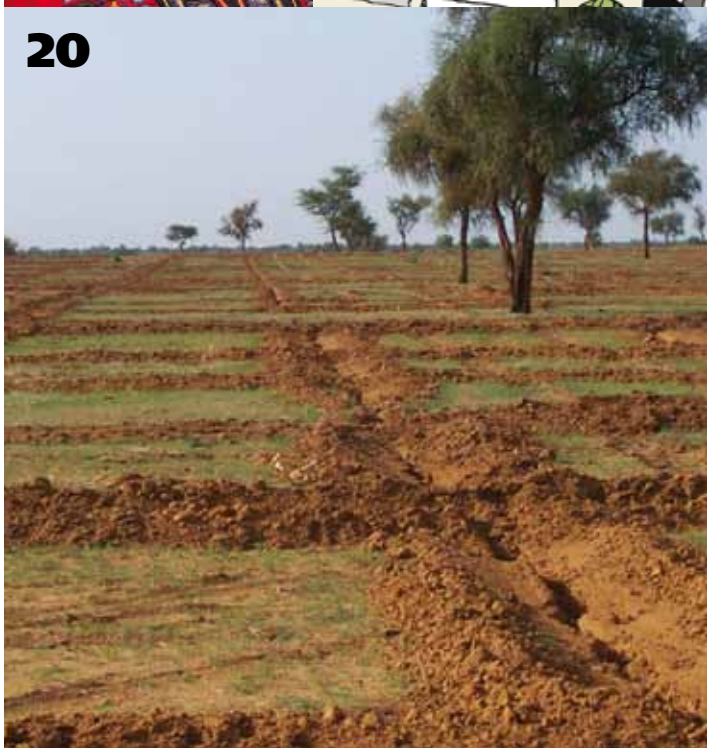
Earth-system science for a sustainable planet

ICSU International Council for Science

Contents

Cover image

The economic paths we choose today will determine future greenhouse-gas emissions. But there is a confusing array of information to make sense of, depicted by the constellation of symbols around the face. On the other hand, the complexity boils down to just two scenarios, depicted by the two globes: continue with business as usual or change.



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

Published by:
IGBP Secretariat,
The Royal Swedish Academy of Sciences
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

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Editorial

Sybil Seitzinger, Executive Director, IGBP

In July 2001, over 1500 scientists from over 100 countries met in Amsterdam for a conference that was to draw attention to the reality of global change – the myriad ways in which human actions are transforming the Earth. The declaration that was signed under the auspices of this conference proclaimed, among other things, the need for a new system of global environmental science to address anthropogenic perturbations of the Earth system. It was recognised that this would require integrating "across disciplines, environment and development issues and the natural and social sciences".

On the back of the conference, the International Council of Science's (ICSU) four international global-change research programmes set up the Earth System Science Partnership to achieve greater coordination. The partnership heralded a new era of closer collaboration and led to the setting up of four joint projects, such as the Global Carbon Project. In addition, the four programmes routinely hold joint conferences and workshops, and co-sponsor core projects. We have made substantial progress, but after almost a decade since the Amsterdam declaration was signed, our research communities have not fully succeeded in transcending the boundaries of disciplines and organisations.

The value of focused, disciplinary research for understanding the Earth system is beyond dispute. But some research communities resist collaborative efforts to tackle issues that naturally cut across disciplines. Others are hampered by lack of resources and by unwieldy management structures at the international level. The current structure for funding global-change research is not conducive to integrative research, and at the university level, research still tends to follow departmental lines. The result of all of this is a lack of communication between different disciplines. As Elinor Ostrom says in an interview on page 8, "A major challenge for such programmes is to develop a common language that crosses disciplines."

IGBP, along with its partner programmes, is keen to collaborate with individuals and organisations to confront this challenge. An important step in this direction on our part is our second synthesis (see back cover of this issue): each of the topics constituting the synthesis requires interaction and knowledge sharing, not only among the different scientific disciplines, but also among scientists, policymakers and other stakeholders around the world. Integrative research and the science-policy interface is also the central theme of a major conference in London to be held in 2012, which will be sponsored by the four global-environmental-change research programmes and their Earth System Science Partnership.

Another way that IGBP is engaging a diverse community of stakeholders is by providing a forum – the *Global Change* magazine – for discussing the issues that cut across disciplinary boundaries. Indeed, the themes addressed in the current issue are as diverse as governance, emissions scenarios and climate scepticism.

Feedback on our December 2009 issue of the magazine has been overwhelmingly positive and has motivated us to keep highlighting themes of interest to a broad readership involved in global-change research. We hope that you find this issue interesting and informative.

> "Our research communities have not fully succeeded in transcending the boundaries of disciplines.

NOAA

Observations task force announced

SCIENTISTS studying the Earth system pull together data from many sources. Developing and testing Earth-system concepts and models often requires merging of data sets from observing systems in ways that frequently result in a lack of precision. This means that only the largest and most obvious consequences of global change can be studied and understood.

Moreover, *in situ* monitoring and measuring stations are often not linked to satellite instruments, but satellites usually require ground-based calibration and verification.

These problems have led to a call for coordinated measurements and networks of measurement sites. At its Scientific Committee meeting in Grenoble, 2010, IGBP announced it would create a task force on observations. This task force – led by Dave Schimel, chair of IGBP's Analysis, Integration and Modelling of the Earth System (AIMES) project – will identify a set of integrative science issues and questions, and the required measurements to support them. It will work to devise an integrative observation strategy.

The task force has already identified the flow of energy and matter between land and oceans, for example, nitrogen and dust flows, as being particularly important.

All IGBP projects, partner programmes as well as the Group on Earth Observations (GEO), NASA and the European Space Agency (ESA) will be invited to participate.

New home for SOLAS International Project Office

THE International Project Office of SOLAS (Surface Ocean – Lower Atmosphere Study) moved to Kiel, Germany, in April 2010 to be co-located with the project's Chair, Doug Wallace. The office will be hosted by the Kiel Leibniz-Institut für Meereswissenschaften (IFM-GEOMAR) and supported by IFM-GEOMAR and the German Ministry of Education and Research, BMBF. The UK Natural Environment Research Council (NERC) will continue to support the UK node of the project office (one position) at the University of East Anglia until 2012.

AN EYE ON THE SINK

Arne Körtzinger

BY ABSORBING substantial quantities of carbon dioxide, the Earth's oceans help in slowing down the increases in atmospheric concentrations of this greenhouse gas. But how the uptake of carbon dioxide varies with location and time remains poorly understood. Recent measurements in the North Atlantic Ocean, reported in *Science*, suggest that the capacity of this carbon-dioxide sink varies considerably on a decadal timescale.

Researchers led by Andrew Watson of the University of East Anglia, United Kingdom, used ship-based measurements to quantify the exchange of carbon dioxide between the atmosphere and the surface of the North Atlantic Ocean. They found that, over a substantial region, the yearly flux between 2002 and 2007 – the longest period for which measurements were available – differed by more than a factor of two. This could be due to natural climate variability, but the exact explanation awaits additional research.

This work also demonstrates that sensors fitted on commercial ships can define the uptake by the North Atlantic with a precision of about 10 percent; an observation system constituted by such ships in various oceans has the potential to provide quantitative constraints on the oceanic sink of carbon dioxide, according to the researchers.

Watson A J *et al.* (2009), *Science* 326: 1391-1393.

The research was conducted under the auspices of the CARBOOCEAN project, endorsed by IGBP's Surface Ocean – Lower Atmosphere Study (SOLAS) project.

IGBP DIARY

2010

June

7-8. PAGES Scientific Steering Committee meeting. Nagoya, Japan. This will be preceded by a workshop on 5-6 June.

8-12. International Polar Year Oslo Science Conference. Oslo, Norway.

13-18. Goldschmidt 2010: Earth, Energy, and the Environment. Knoxville, Tennessee, USA.

22. ICSU Open Forum on Institutional Support for the Grand Challenges. Paris, France.

July

11-16. 11th IGAC conference with CACGP. Halifax, Canada.

September

13-17. LOICZ Storm Surges Congress 2010. Hamburg, Germany.

13-15. PAGES Symposium. Global Monsoon and Low-Latitude Processes: Evolution and Variability. Shanghai, China.

14-16. SCOR General Meeting. Toulouse, France.

October

10-14. IMBER Imbizo II. Integrating Biogeochemistry and Ecosystems in a Changing Ocean: Regional Comparisons. Crete, Greece.

12-14. International Workshop on ENSO, Decadal variability and climate change in South America. Guayaquil, Ecuador.

17-19. GLP Open Science Meeting. Land Systems, Global Change and Sustainability. Tempe, Arizona, USA.

November

3-9. Earth Observation for Land-Ocean Interaction Science. Frascati (Rome), Italy. Co-sponsored by iLEAPS.

Major global change conference in 2012

THE UK will host a major international science conference in 2012. The London conference, Planet Under Pressure: New knowledge towards solutions, aims to attract 2500 of the world's leading thinkers on global-change research.

The four-day conference is sponsored by the International Council for Science's (ICSU) global-environmental-change research programmes. It will bring together a diverse set of individuals interested in global-change issues, including natural and social scientists, economists, engineers, national and international policymakers, industry representatives and NGOs.

The event, provisionally booked for 7-10 May 2012, will take place prior to the next UN Earth Summit in Rio de Janeiro, also scheduled for that year. Presenting the latest research findings, the London conference is anticipated to provide a solid scientific foundation for the summit.

IGBP Executive Director Professor Sybil Seitzinger says, "We need to communicate a comprehensive picture of the state of the planet and its future to the institutions charged with global environmental stewardship."

"We will work with these institutions to help develop a planetary management approach that tackles all the challenges in a truly integrated way," she added.

The conference will be hosted by the UK's Royal Society, the Living With Environmental Change programme (LWEC, which represents all the UK's main agencies and government departments tackling environmental change) and the Natural Environment Research Council (NERC), the UK's largest funder of environmental science.

ACIDIFYING OCEANS

ONGOING acidification of the Earth's oceans may impair the ability of some marine organisms to make their calcium carbonate skeletons. According to a recent study in *Nature Geoscience*, the impacts of the current phase of acidification are likely to be more severe than those associated with a similar event that occurred some 55 million years ago, at the Palaeocene-Eocene boundary.

Andy Ridgwell and Daniela Schmidt of the University of Bristol, United Kingdom simulated and compared the response of the ocean to increased acidification in the future and at the Palaeocene-Eocene boundary. Assuming that atmospheric carbon dioxide concentrations will peak around the year 2150, they found that conditions favourable for the formation of calcium carbonate (calcite) skeletons become on average restricted to the upper-most 600 m of the ocean – as opposed to 4 km for the modern ocean. This change in ocean conditions occurs far more rapidly than estimated for the Palaeocene-Eocene boundary.

Marine organisms residing in the deep-sea sediment – also called benthic organisms – were particularly affected at the Palaeocene-Eocene boundary, leading to extinction. This has the potential to recur if the modern phase of acidification continues. Not only that, but the capacity of surface-dwelling micro-organisms to adapt to such changes will also be severely tested, say the researchers.

Ridgwell A, Schmidt D (2010), *Nature Geoscience* DOI: 10.1038/NGEO755.

This work arose out of the IGBP-SCOR (Scientific Committee on Oceanic Research) Fast-Track Initiative on Past Ocean Acidification.

Stockholm to house new international office

IN HUMAN history, some societies collapsed catastrophically, while others blossomed and grew. A complex web connects societies with their environments in every dimension – economic, social, political, spiritual and philosophical – and is critical to building long-term social-ecological resilience. A new project, Integrated History and future Of People on Earth (IHOPE), fosters a global network of researchers and research projects that share knowledge about the past to enable a sustainable future for humanity and our planet. IHOPE facilitates interaction among the social sciences, humanities, modelling and biophysical communities to identify key variables and conditions of these historic complex systems to address future changes.

IHOPE was initiated and has operated for the past several years under the auspices of the Analysis, Integration and Modelling of the Earth System (AIMES) core project of IGBP. It is co-sponsored by AIMES, the Past Global Changes (PAGES) core project of IGBP, and the International Human Dimensions Programme on Global Environmental Change (IHDP).

IHOPE's International Project Office is hosted at the Stockholm Resilience Centre (SRC), Stockholm University (Sweden). The centre provides central coordination, communication and integration for the IHOPE community and infrastructure. It will also support the implementation of the recently published science plan. Carole Crumley and Stephen Barthel manage the International Project Office at the centre and Kathy Hibbard and Jennie Rice contribute on behalf of AIMES.

See: http://stockholmresilience.org/ihope

IGBP statement in support of IPCC

ON 3 May, IGBP released a statement emphasising that the IPCC process for assessing climate change, its causes, impacts and responses, is reliable and unbiased. The statement was in response to criticism thrown at the IPCC in the wake of its admission of a small number of errors in its Fourth Assessment Report. Research conducted by IGBP's network of scientists in 74 countries has been assessed by all four IPCC reports. The full statement is available on the IGBP website.

New vision for Earth-system science coming soon

THE International Council for Science (ICSU) is set to announce its new vision for Earth-system science in June. The team tasked with developing the vision has produced a draft document outlining the five challenges in global sustainability research for the next decade. The outcome could have a large bearing on the future of IGBP and its projects.

In a high-level meeting scheduled for 23-24 June 2010, ICSU will discuss which types of institutional arrangements will be needed to support the research strategy. Representatives from the four global-environmental-change programmes as well as their co-sponsors, funding agencies and other organisations will participate. An Open Consultative Forum in Paris will be held on 22 June 2010, in conjunction with the co-sponsors' meeting, to consider institutional support for the research priorities.

http://www.icsu-visioning.org/the-visioning-process/

IMMIGRANT OZONE?

OZONE from Asia may be finding its way to western North America and raising springtime tropospheric ozone levels in this region, according to measurements reported in *Nature*. High concentrations of ozone in the troposphere – the lowermost layer of Earth's atmosphere – are considered to be harmful to human health and vegetation.

Stringent regulations have helped improve air quality in Europe and North America during the past few decades. The emissions of nitrogen oxides, which go on to form ozone, have decreased as a result. This is not the case for Asia, however, where emissions have increased considerably in recent years: prevailing winds are expected to transport ozone produced in Asia to North America. But previous work had not recorded clear increases in tropospheric ozone over western North America.

Springtime ozone concentrations measured by Owen Cooper from the University of Colorado and colleagues now show distinct increases for the 1995-2008 period in the region 3-8 km above the surface of western North America. The trend is even more pronounced when data for only the air masses from Asia are considered, implicating Asian ozone. However, further research is required to determine how much of this ozone reaches the surface of North America. In a related article in the same journal, Kathy Law of the Université Pierre et Marie Curie in Paris, France, points out that the clarification of the role of Asian ozone was possible in this case due to the large dataset that was used in the study.

Law calls for measurements in seasons other than spring and additional work to uncover the mechanisms underlying the trends observed by Cooper and colleagues. But she highlights the utility of programmes that make long-term measurements, both for testing climate models and monitoring changes in the concentrations of atmospheric gases.

These results reveal the limitations of purely national approaches to pollution control, and point to the necessity of an effective international regulatory framework.

Cooper O R *et al.* (2010) *Nature* 463: 344-348; Law K (2010) *Nature* 463: 307-308.

Kathy Law is a former chair of IGBP's International Global Atmospheric Chemistry (IGAC) project. Some of the paper's authors are associated with IGAC.

Events

2010

June

29 June-1 July. 2010 International Climate Change Adaptation Conference. Climate Adaptation Futures: Preparing for the Unavoidable Impacts of Climate Change. Gold Coast, Queensland, Australia.

July

5-7. NCAR Atmospheric Science Conference 2010. Manchester, United Kingdom.

September

13-16. 3rd Bi-Annual Symposium: The Future Ocean. Kiel, Germany.

29 September-1 October. Deltas in Times of Climate Change. Rotterdam, the Netherlands.

October

4-13. 2010 Marie Curie training course on Architectures for Earth System Governance. Berlin, Germany.

11-14. International River Symposium. Perth, Australia.

26-30. Urban Futures and Human and Ecosystem Wellbeing. Shanghai, China.

November

15-17. Ester Boserup Conference 2010. Long-term Trajectories in Population, Gender Relations, Land Use, and the Environment. Vienna, Austria.

22-26. International Conference on Environment and Resources of the South Pacific. Viña del Mar, Chile.

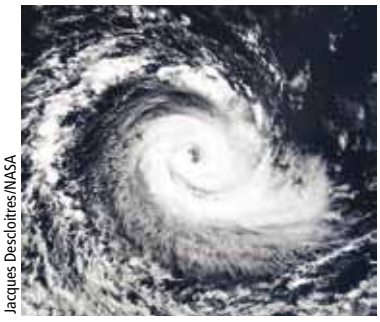
December

3-7. International Nitrogen Conference 2010. New Delhi, India.

6-8. The Global Dimensions of Change in River Basins: Threats, Linkages and Adaptation. Bonn, Germany.

Major science funders call for focus on regional environmental change

IN June 2009, the chief executives of the world's major global-change funding agencies and the International Council for Science (ICSU) met at a high-level forum in Belmont, near Washington DC. The aim of the meeting was to identify strategic priorities for international cooperation. The UK's Natural Environment Research Council (NERC) hosted the second meeting of this 'Belmont Forum' in January 2010, at the UK Royal Society. The meeting identified regional environmental change, in particular human action and adaptation, as a major issue requiring regional and decadal prediction, advanced observing systems and inclusion of the social sciences. Related priority topics include the coastal zone, water cycle and resources, ecosystem services/food security, most vulnerable societies (geographic areas) and the carbon cycle.



Jacques Descloitres/NASA

Climate change and tropical cyclones

AS the climate warms, the globally averaged frequency of tropical cyclones is likely to decrease, suggests a survey of recent work published in the journal *Nature Geoscience*. Rainfall resulting from such cyclones is expected to increase in the future, and an increase in the intensity of the strongest storms is also possible.

Knutson T R *et al.* (2010) *Nature Geoscience* 3: 157-163.

DRYLANDS' DELICATE BALANCE

Weizmann Institute of Science, Israel

DESPITE the fairly inhospitable conditions, forests in semi-arid regions can lock up as much carbon as forests in wetter settings, suggests a study recently published in the journal *Science*. The results emerged from a decade-long measurement programme in the Yatir pine forest in Israel. Dryland forests cover almost half of the Earth's land surface.

The study's authors, Eyal Rotenberg and Dan Yakir of the Weizmann Institute of Science, Israel, measured the flux of carbon dioxide, water vapour and energy to determine the productivity of the Yatir Forest. They found that during the past decade, the forest's net carbon uptake is comparable to that of pine forests in Europe. Dryland forests apparently manage this feat by reducing respiration rates and growing rapidly in early spring to take advantage of temperatures most favourable for growth. Forests such as those in Belgium and Finland, in contrast, achieve maximum growth in the summer.

The drawdown of atmospheric carbon dioxide by dryland forests would be expected to contribute to a net cooling of Earth's climate. But two processes lead to warming and serve to counter the cooling effect of carbon sequestration.

First, being darker than their surroundings, dryland forests enhance the absorption of incoming shortwave solar radiation, leading to warming. Second, dryland forests – by virtue of low tree density and open canopy – are particularly conducive to aerodynamic coupling with the atmosphere. This coupling promotes efficient heat convection and causes localised cooling over the forest canopy. The cooling suppresses the flux of outgoing thermal radiation from the forest surface, also causing net warming.

The authors estimate that after afforestation, it would take about 80 years for the CO_2-absorption-induced climate cooling to balance out the radiative warming effect. Yatir, though, represents an extreme case, and this period can be shorter on average. Elaborating on the significance of the results in a related opinion article in the same journal, David Schimel at the National Ecological Observatory, Colorado, suggests that the benefits of afforestation programmes in drylands – albeit long term – are worth investing in.

The past few decades have witnessed increased desertification globally in semi-arid regions. Rotenberg and Yakir report that this led to lower absorption of incoming solar radiation and enhanced emission of outgoing thermal radiation. As a result, there was some amelioration of the warming induced by increased carbon-dioxide emissions during the same period. Clearly, the role that forests in arid and semi-arid regions play in controlling global climate is a complex one, and deserves closer scrutiny.

Rotenberg E and Yakir D (2010) *Science* 327: 451-454; Schimel D S (2010) *Science* 327: 418-419.

DAN YAKIR is a member of IGBP's Scientific Committee. David Schimel is Co-chair of IGBP's Analysis, Integration and Modelling of the Earth System (AIMES) project.

Reflections on GOVERNANCE

What is the best solution to tackling climate change? There is no panacea, and we have to experiment with multiple approaches, **Elinor Ostrom** tells **Ninad Bondre**

Despite much discussion and heated arguments, the climate change conference at Copenhagen failed to bring about a binding agreement on cutting greenhouse-gas emissions. Frustrated by this outcome, some in the global-change community have begun to question the adequacy of the existing international framework to address the challenges posed by climate change. The assumption that the international arena is the only one to take action on climate change, however, seems to be deeply rooted. Elinor Ostrom of Indiana University, USA, and winner of the 2009 Nobel Prize in Economics, has devoted much of her academic career to understanding the governance structures that evolve to manage common property. Her most recent work looks at how a polycentric approach – an approach that involves efforts at local, regional as well as global scales – can be applied to solving issues arising from anthropogenic climate change.

Winning the Nobel Prize in economics must have really put the spotlight on you.

Yes, the past few months have been very busy. I am still getting requests for travel in 2010, at a rate of three or four a day. But my travel itinerary for the year is already fully booked.

Your work over the past decades has highlighted many examples where local communities organised themselves to manage natural resources sustainably. Do local communities do a better job of managing resources than national governments?

That depends very much on the specific context. Decentralisation has become somewhat of a mantra in the recent past, and there is a tendency to consider this as a panacea. But this is just as naïve as saying that the solution to resource-management problems is centralisation. Local management has its benefits but it cannot be used as a quick and dirty blueprint to solve all problems.

There are parts of the world where people had centuries of experience in managing the natural resources that they depended on. In many instances, the resources were taken away from them. If we are to now return the control over the resources to the communities, several questions need to be answered. For example, how long has it been since the resource in question was taken away from the community? Does the community still have people with the indigenous knowledge that would be essential to manage the resources? I have gone to meetings where forest officials have simply said: "Now it's yours". But they forget that what is being handed over is often a resource that has been degraded by years or decades of poor management. It does not make sense to abruptly transfer it to local communities and expect miracles.

Following up on that, you have cautioned against the tendency to believe in panaceas for problems of sustainable management of social-ecological systems.

Yes, this is addressed in a 2007 special feature in the *Proceedings of the National Academy of Sciences*, entitled "Going beyond panaceas". Studies in this issue highlight the pitfalls in governance approaches informed by notions of a universal remedy. At one end of the spectrum, the belief that government ownership is the best way to manage natural resources – forests, for example – has in some cases led to a marked reduction in the resource.

Social-ecological systems are not amenable to being characterised by simple models.

Elinor Ostrom will serve as the Chief Scientific Advisor of the global-change Open Science Conference to be held in 2012.

At the other end, imposing decentralisation as a remedy without a proper understanding of the local society has triggered ethnic conflict. Social-ecological systems are complex and nested, and resource users around the world vary widely in their preferences and perceptions. Such systems are not amenable to being characterised by simple models.

Global commons – resources that are shared by the world – pose special challenges, which you have alluded to in your 1999 *Science* article. What have we learned about the management of such resources in the past decade?

We have found that the oceans and the atmosphere are fundamentally different when it comes to applying local strategies to solve global problems.

For the oceans, we do not yet have many local-scale experiments, the results of which would apply globally. Community management works well in the case of coastal fisheries, where people can know one another, sell their fish in one place and where there can be monitoring. This is difficult to achieve at the global scale.

I would encourage efforts at all scales: local, regional and global.

Flawed top-down approach

In the 1980s, the Department of Fisheries and Oceans in Canada used its own model for stock regeneration of northern cod, overriding the concerns about collapse raised by local fishers. The stock collapsed soon after, in 1992, compelling the government to suspend cod fishing in Canadian waters. This came at a considerable cost to local fishing villages that had managed fish stocks effectively until then.

For more details and references see Ostrom E (2009) "A polycentric approach for coping with climate change". Policy research working paper WPS5095. The World Bank.

In the case of the atmosphere, steps taken at the individual and community levels can have global impacts. For example, an immense amount of energy goes into heating buildings, and local actions aimed at reducing such consumption can be very effective in reducing greenhouse-gas emissions globally. Actions at the local scale do not necessarily solve the global problems; global action is also needed. But we could be taking many more steps locally and regionally, and indeed, more and more are being taken.

The Copenhagen conference is being viewed in some quarters as a failure due to the inability to reach an international agreement. Do you think that the exclusive focus on a global agreement is inhibiting actions at other levels?

Absolutely. If we think that action is important only at a global scale, we are sitting around twiddling our thumbs when we could do much more. I would encourage efforts at all scales: local, regional and global. The problem of reducing greenhouse-gas emissions has been framed exclusively as a global issue; as a result, it is sometimes difficult for policymakers and citizens to appreciate that there are many important actions that can be taken at the local scale. This was one of the difficulties that the Cities for Climate Protection campaign faced. Yet, there are several examples of successful efforts to reduce greenhouse-gas emissions that are being taken at local and regional scales, which I discuss in a policy paper that I wrote for the World Bank last year, entitled "A Polycentric Approach for Coping with Climate Change".

It is a fact that international efforts during the past several decades have failed to come up with a fair and enforceable agreement on reducing greenhouse-gas emissions. It is not

A win-win situation for forests

Forests are a source of livelihood for tens of millions of people around the world. And by drawing down atmospheric carbon dioxide, they also contribute to stabilising greenhouse-gas concentrations. But whether these two types of benefits go hand in hand or conflict with each other remains to be fully understood. To shed more light on this issue, researchers recently analysed data for 80 forests in 10 different countries. They focused on three aspects: forest size, autonomy at the local level to make rules regarding forest management, and ownership (whether by local communities or by national governments). They found that a combination of larger forests and greater local autonomy lead to above-average benefits in terms of livelihood as well as carbon storage. Government ownership was found to result in high livelihood benefits, but this came at a cost to carbon storage. The researchers suggest that international initiatives aimed at reducing emissions by encouraging forest preservation should explore the option of transferring the ownership and management of larger tracts of forests to local communities.

Chhatre A and Agarwal A (2009) *Proceedings of the National Academy of Sciences* 106: 17667-17670.

advisable to wait for the perfect global agreement while ignoring important actions regarding adaptation and mitigation that could be taken at other levels. But not only this, there is empirical evidence to suggest that problems have been addressed successfully as well as unsuccessfully at all scales – local, national and international. The polycentric approach advocates complex, multi-level systems to tackle what is a complex, multi-level problem. Given the nature of the problem, building the system required to execute this approach will of course take time, but recognising the need for such an approach is important enough.


Elinor Ostrom during the 2007 Resilience conference in Stockholm.

Governance is the subject of ongoing research. But would it be correct to say that trying and testing various systems should continue in parallel?
Yes. We do need as good a foundation as possible to base action on. But there are some scientific questions that will take us a while to answer. Meanwhile, we should be experimenting with diverse institutional changes, and monitoring them carefully so that we can learn from such experiments. Simple mathematical models can work very well for some questions but often do not work that well with complex systems and in evaluating policy choices. Concrete actions and experimentation can help us to understand why the changes work in particular contexts and not in others.

You have spoken about the need for embracing the concept of social-ecological systems. Do you think international programmes such as IGBP are doing enough?
I think that they could do more. A major challenge for such programmes is to develop a common language that crosses disciplines. Disciplinary boundaries tend to be etched in stone, and there is a big divide between the social sciences and the ecological sciences, which have developed independently. We need to get a real conversation going between these two broader disciplines. Social-ecological systems represent a complex whole, but different disciplines approach such systems in diverse ways. Some of my recent work, and that of others, has focused on how we can develop a common language that will help us move forward, and I am currently developing this further with colleagues in Europe. In fact, they are beginning to use this framework to design new empirical research. ▮

We should be experimenting with diverse institutional changes.

NINAD BONDRE is Science Editor at IGBP.

States and cities impose effective energy policies

In 2006, the State of California passed a law aimed at reducing greenhouse-gas emissions in the state and bringing them down to 1990 levels by 2020 (a reduction of approximately 25 percent; see http://www.arb.ca.gov/cc/facts/facts.htm for details). This entails substantial cuts by major industries. The state seeks to achieve this by a market-based, cap-and-trade programme.

Local governments in Denmark operate plants that incinerate household waste to generate power and heat. The Horsholm plant, for example, is owned by five different local communities. As The *New York Times* reports, "Sixty-one percent of the town's waste is recycled and 34 percent is incinerated at waste-to-energy plants." The advantages that the plants provide in terms of waste disposal and cheap heating ensure that most communities in Denmark are eager to have such plants in their neighbourhoods.

FOR MORE INFORMATION
see http://www.nytimes.com/2010/04/13/science/earth/13trash.ml?pagewanted=1&ref=earth.

ONE planet, FOUR futures

How will our complex societies and economies respond to climate change? So far, future climate scenarios have not adequately included emissions-reductions policies and adaptation. All that is about to change. **Owen Gaffney** reports.

In February, President Barack Obama announced his intention to build two new nuclear power stations on US soil. If this happens, these will be the first nuclear power stations commissioned in the US since the Three-Mile Island nuclear disaster in Pennsylvania in 1979.

The announcement along with legislation to curb greenhouse-gas emissions could mark a turning point in US policy. Maybe the rest of the world will follow suit, and we will soon be on track to reduce emissions by 80 percent by 2050. By the end of the century, carbon-dioxide emissions may stabilise at what is considered an acceptable level.

Alternatively, public outcry in the US at the mere thought of nuclear will deal it a fatal blow. Other legislation will fail. Emissions will continue unabated or, in the jargon of the climate policy people, the world remains on the "business as usual" track.

These are two possible options for the planet's future greenhouse-gas emissions. There are many more. A new technology may appear eliminating the need for fossil fuels. The story is often recounted of how New Yorkers once complained of the mountain of horse manure building up in the city. Before long, some claimed, manure would reach the first floors of many buildings. Then, Henry Ford's internal combustion engine trundled into town. No similar game-changing technology is in sight, yet.

This uncertainty about which direction society will lurch is a massive challenge for climate researchers.

Exploring scenarios

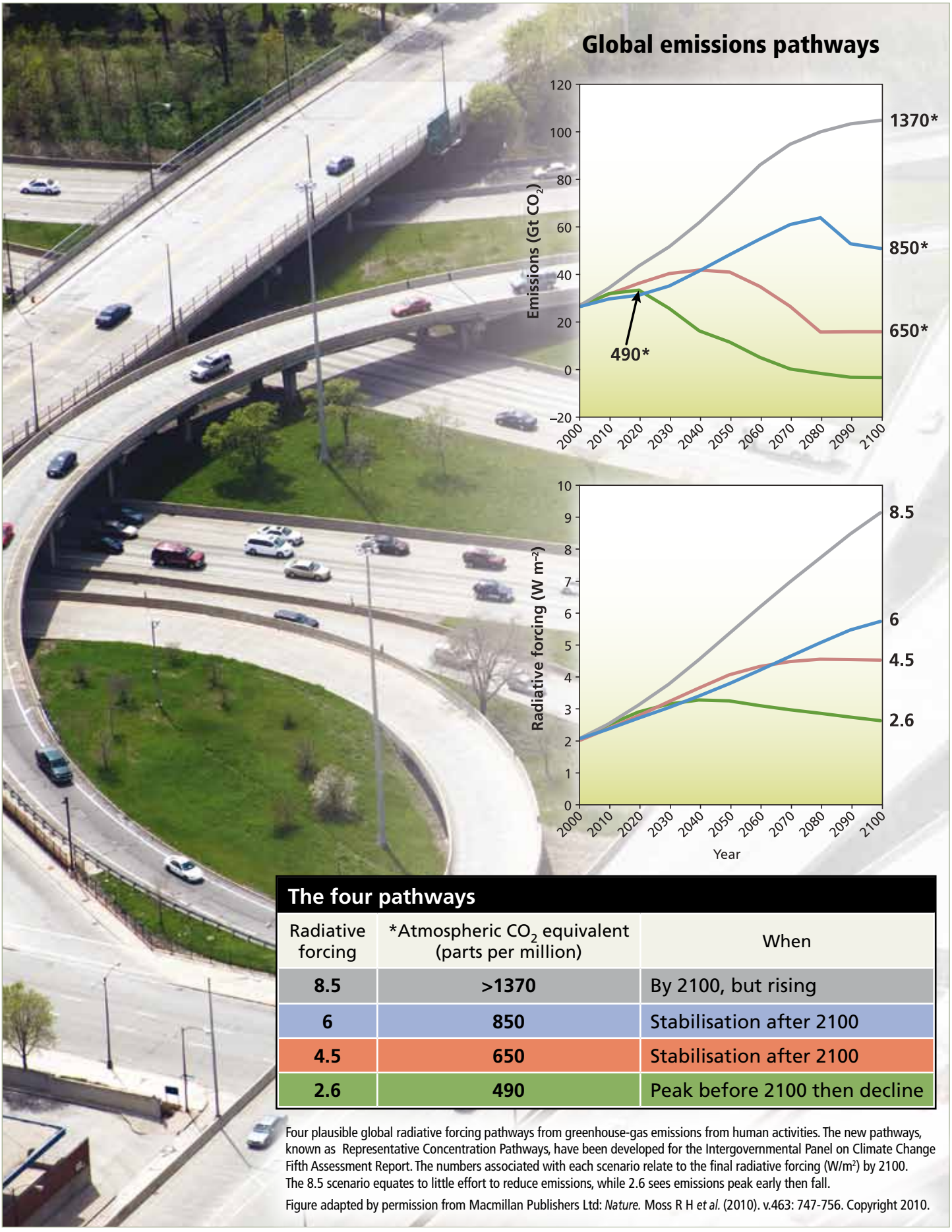
This uncertainty about which direction society will lurch is a massive challenge for climate researchers. It is impossible to pin down a single route, so economists, energy experts and others develop a range of realistic possibilities or scenarios. Climate researchers feed these scenarios into climate models that output likely ranges for global temperature, rain and snowfall and other climate parameters. Specialists in ecosystems, agriculture, water, city planning, economics and other areas take this information and assess impacts and costs.

The importance of these scenarios cannot be overstated. They provide a range of options for the world's governments and other institutions. Some of these options will require the wholesale upheaval of the global energy system, upon which industrialisation has depended. Some options, for example business as usual, require little action.

The pathway society chooses to follow will have profound consequences for developed and developing economies alike. The Global Carbon Project's recent carbon budget shows the business-as-usual option seems to be society's preferred choice for now. This choice has been made despite warnings based on robust and comprehensive scenarios published in the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Now, a new way of developing scenarios has been created.

In the past, IPCC had a cumbersome system for turning predictions of energy demands, population growth and political leadership into atmospheric emissions and finally vulnerability assessments.

First, researchers drew up complex future economic scenarios. Second, these families of scenarios – the famous SRES families (Special Report on



The four pathways

Radiative forcing	*Atmospheric CO_2 equivalent (parts per million)	When
8.5	>1370	By 2100, but rising
6	850	Stabilisation after 2100
4.5	650	Stabilisation after 2100
2.6	490	Peak before 2100 then decline

Four plausible global radiative forcing pathways from greenhouse-gas emissions from human activities. The new pathways, known as Representative Concentration Pathways, have been developed for the Intergovernmental Panel on Climate Change Fifth Assessment Report. The numbers associated with each scenario relate to the final radiative forcing (W/m^2) by 2100. The 8.5 scenario equates to little effort to reduce emissions, while 2.6 sees emissions peak early then fall.

Emissions Scenarios) – fed into climate models. Third, the models informed specialists on impacts, vulnerability and adaptation.

Emissions scenarios emerging in 1997 were used in climate models assessed in the 2001 IPCC Third Assessment Report. Remarkably, scientists from IPCC's Working Group Two (WGII) studying vulnerability, impact and adaptation to climate change had to wait six years, until the 2007 report, to publish assessments of the same scenarios. This complicated how costs and benefits of climate change were calculated because the other two IPCC working groups were already reporting on new scenarios (WGI deals with the physical basis of climate change, WGIII handles mitigation).

IPCC needed something more responsive, and besides, the SRES families had a perceived major drawback: they did not include mitigation. IPCC decided to drop the problem in the laps of the research community. An international group coordinated the work. This was led by IGBP's Earth system modelling project, Analysis, Integration and Modelling of the Earth System (AIMES), the World Climate Research Programme's Working Group on Coupled Modelling (WGCM) and the Integrated Assessment Modelling Consortium. The result was published in the journal *Nature* in February 2010 in a paper entitled "The next generation of scenarios for climate change research and assessment".

The new approach

It all kicked off in summer 2006 with a meeting in Aspen, Colorado. Lead author Richard Moss, from the Joint Global Change Research Institute based at the University of Maryland in the US, explains, "We brought together a range of different modelling communities: climate, chemistry, carbon cycle, terrestrial modellers, land-use specialists, as well as people from the social science side working on emissions, economics, policy, vulnerability and impacts."

Later, in 2007, more than 150 researchers met in the Netherlands.

The outcome was a rethinking of the entire process. The group came up with the idea of starting with atmospheric concentrations of greenhouse gases rather than detailed socio-economic processes. Climate researcher Nebojsa "Naki" Nakicenovic representing IPCC's WGIII argued that IPCC's old emissions scenarios failed to include mitigation. What happens, he asked, if emissions peak then begin falling? The group concluded that some of the new scenarios should take this into account.

The series of meetings pared down 324 published emissions pathways to just four. The pathways finish in 2100, where the complexity of humanity's future emissions is distilled down to four numbers. These are based on the extra heat, or radiative forcing, the lower atmosphere will retain as a result of additional greenhouse gases, measured in Watts per metre squared (W/m^2).

The new pathways result in 2.6, 4.5, 6.0 and 8.5 W/m^2 as plausible outcomes by 2100. Earth's radiative forcing is now around 1.6 W/m^2 greater than at the start of the industrial revolution. The four pathways are based on greenhouse-gas emissions that would result in peak atmospheric emissions concentrations equivalent to 490, 650, 850 and over 1370 parts per million CO_2 respectively. The new scenarios were named "representative concentration pathways", or RCPs.

Moss explains, "At the core of the new approach is humans' total radiative forcing on the atmosphere over time."

It was decided four RCPs were enough. AIMES Executive Officer Kathy Hibbard says, "Preliminary results showed that as far as global temperature goes, if radiative-forcing predictions are too close, the span of possible global temperature ranges overlaps too much."

Computer power was another consideration. Earth-system computer models are now so complex that more scenarios would eat up too much computing time.

The complexity of humanity's future emissions is distilled down to four numbers.

A significant improvement

The scientists are sure the new approach is a big improvement on its predecessor. While the four pathways allow researchers to develop climate-model scenarios, they do not constrain future work on integrated assessments. These researchers will simultaneously develop a range of completely new socioeconomic and emissions scenarios. They will have complete freedom to develop these new scenarios which will allow them to explore alternative technological, socioeconomic and policy futures.

The researchers believe that the parallel process is a significant improvement for several reasons. First, climate model simulations no longer need to be rerun each time emissions scenarios change. In the past, when the socioeconomic scenarios were modified, the climate model simulations were run again, even though the changes seldom resulted in detectable alterations to the modelled future climates. Indeed, many socioeconomic projections can lead to very similar concentration trajectories.

Eliminating the need to rerun models for each new scenario will save considerably on computing time. The plan is to use this time to generate larger ensembles (running the same model many, many times) at higher resolution. It is anticipated this will lead to better simulations of regional

change and extreme events, and more robust understanding of the uncertainties.

Second, in the future, as climate models improve, the newer updated climate models can be run using the same pathways, allowing modellers to isolate the effects of changes in the climate models themselves.

Third, researchers working on impacts, adaptation and vulnerability will get model outputs from climate modellers and emissions and socioeconomic modellers much earlier.

If successful, this approach will be a marked improvement on the previous assessments, and allow WGII more time to complete its part of the Fifth Assessment Report.

At the highest end of the scale, the 8.5 pathway represents a failure to curb emissions. Emissions do not stabilise: they rise beyond 2100.

But is 8.5 still too low given the upshot of the climate negotiations in Copenhagen, the US's internal struggle to curb emissions, the fallout from IPCC's minor blunders and the public outcry at the content of hacked emails from the University of East Anglia?

"Some wanted a much higher radiative forcing. The policy people did not want to hear that," says Hibbard.

But Moss, while not ruling out a higher value, thinks 8.5 is a reasonable upper bound. "You'd have to work hard to get to 8.5. It means burning a lot of coal. Of course, if we get certain feedbacks like more methane escaping from the seabed or forest die-back then this could go higher."

The most ambitious pathway, 2.6, also led to heated debate. Initially, scientists suggested a lowest scenario of 2.9. But policymakers pushed for a harder target claiming society needed a tough goal.

Hibbard says, "The policy people said 2.9 did not represent the full range. It was a charged environment with meetings going into the early morning."

Scientists felt anything below 3 W/m^2 will be tough to achieve. Eventually, the European Union commissioned two groups to redo the analysis. From this there was agreement that 2.6 was possible and it became the fourth pathway. But, 2.6 is going to be difficult if you exclude geoengineering options or some new technology.

"To make 2.6, we'd need universal participation from all the main emitters very soon, including those in developing countries," says Moss. Among many assumptions, it could mean global meat consumption would need to almost reach zero by 2100 – livestock accounts for 18 percent of greenhouse-gas emissions when you factor in the clearing of forested land, making and transporting fertiliser, burning fossil fuels in farm vehicles and the front- and rear-end emissions of cattle and sheep.

A second element of the scenarios is a new focus on atmospheric emissions up to 2035, as well as 2100. This satisfies policymakers' requests for decadal climate predictions. Up to 2035, the four RCP are tightly grouped, so researchers only need to examine one scenario – 4.5. "This frees up processing power and you can work at higher resolution with the expectation that this will provide better information for planning adaptation options in the near term," explains Moss.

An immediate benefit of the RCPs is that they are bringing together a diverse range of research communities. This is an essential step in the drive to create fully integrated Earth-system models that go beyond general circulation models to include the global economy and society, impacts and vulnerabilities.

Beyond this, the outcome of the Copenhagen climate talks notwithstanding, humanity seems to be gearing up to set emissions targets.

Producing future scenarios

Producing future scenarios for climate-change research requires three approaches: integrated assessments, climate models and impact assessments.

Integrated assessments include the main features of human systems: demography, energy use, technology, the economy, agriculture, forestry and land use. They split the world into a dozen or more regions with time steps of about a decade. Some include a rudimentary climate system, ecosystems and climate impacts.

Climate models have a wide variety and complexity. The most complex simulate interactions between the atmosphere, oceans, land and ice. Earth-system models also include additional ecological and chemical processes.

Impact assessments focus on adaptation and vulnerability to climate change. They use a range of approaches to explore the consequences of climate change for agriculture, water resources, human health, ecosystems and coastal infrastructure. Economic evaluation is an important part of this work.

"Science is not going to tell us which trajectory we need to be on," says Moss. "That is a policy decision based on how much risk we want to take and what we value – economic growth? Ecosystems?"

But, it seems certain that global and national emissions controls will be influenced strongly by these kinds of scenarios. Scientists realise this and are careful to avoid any accusation that they are advocating one scenario over another. Indeed, this is reflected in one rationale for choosing four RCPs instead of three.

"We decided on four because if you choose three, people will assume society should aim for the middle," says Hibbard. ▮

Science is not going to tell us which trajectory we need to be on.

OWEN GAFFNEY is Director of Communications at IGBP.

Moss R H *et al.* (2010) The next generation of scenarios for climate change research and assessment. *Nature* 463: 747-756.

Whence climate scepticism?

Leaked emails hacked from the servers of the University of East Anglia have re-energised climate sceptics. Because the roots of such scepticism lie in a polarised political climate, it needs to be countered by a change in discourse and not just a reiteration of facts, argues **Ninad Bondre.**

The media frenzy triggered by leaked emails from the University of East Anglia (UK) was further fuelled by the discovery of a few mistakes in the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC). Those challenging a human role in climate change launched scathing attacks that were high on sarcasm and drama. The events began just before the climate conference in Copenhagen and continue in the run up to the debate on what could be a seminal climate bill on the floor of the United States Senate. The significance of the timing is difficult to miss.

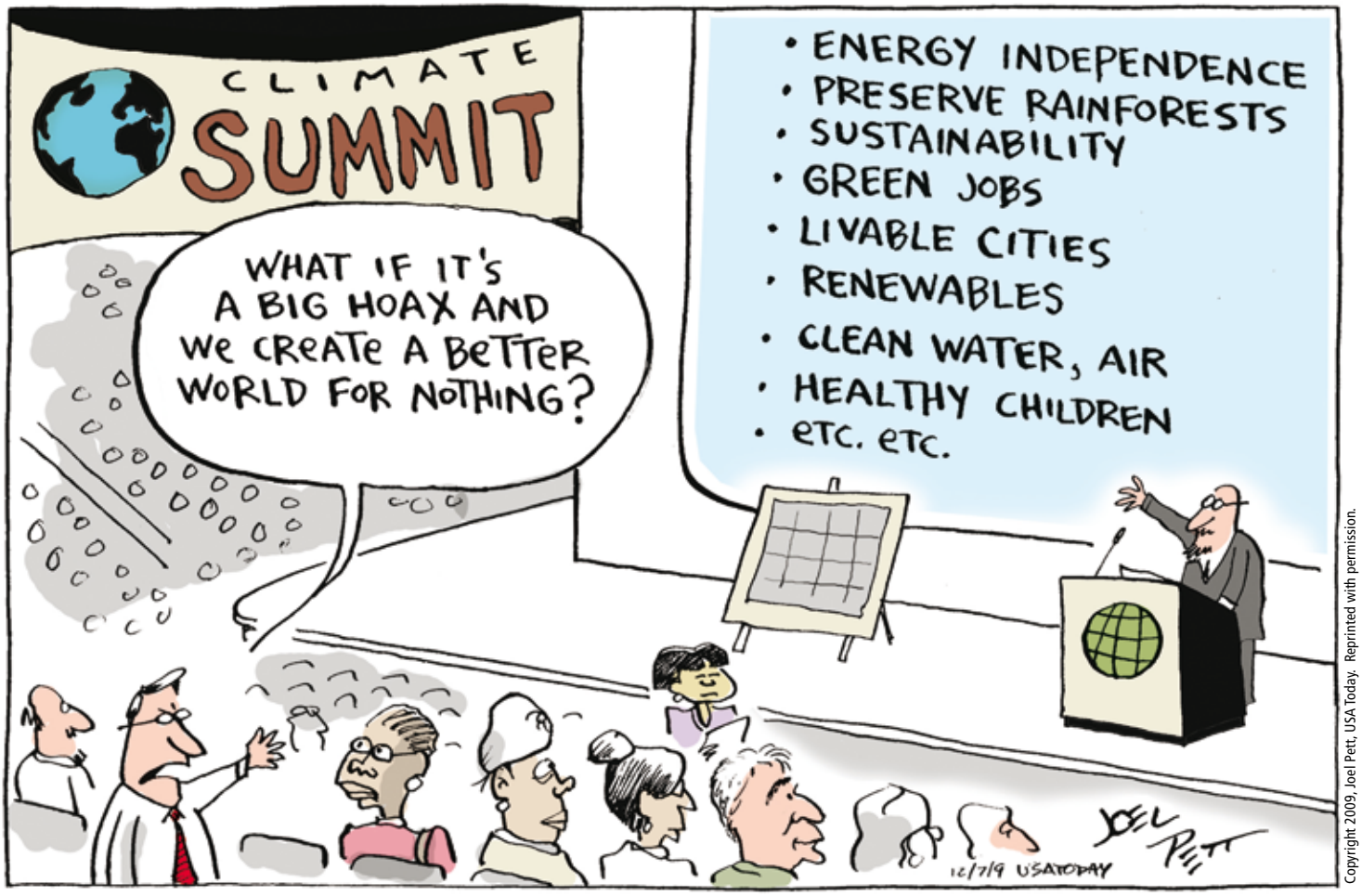
Many within the global-change community seem to be attributing this sequence of events to a failure of scientists to communicate climate science. There have been calls for climate scientists to engage with the media more directly, be more transparent and better communicate the uncertainties in their research. Others are exhorting the media to undertake investigative journalism of the sort that characterises the coverage of other issues.

Is the opposition of sceptics due to poor communication?

Better communication would certainly help, but is the opposition of sceptics merely the result of paucity of facts or due to poor communication? Barring a few individuals (Bill McKibben on TomDispatch.com; Daniel Sarewitz, *Nature* 464: 28), few have called for a deeper understanding of how a virulent brand of climate scepticism has arisen and what social and political conditions have allowed it to thrive.

Modern-day climate sceptics

Scepticism about anthropogenic climate change is nothing new – in fact, the first sceptics were quite likely climate scientists themselves. After all, Earth's climate is incredibly complex: to hold human actions – particularly the burning of fossil fuels – responsible for a changing climate requires strong scientific evidence. Such evidence now exists, as summarised by the Intergovernmental Panel on Climate Change (IPCC), for example. Although scientists do not comprehend fully the complexity of climate, the information at their disposal clearly indicates that humans have been key players in driving climate change over the past century or so. Of course, a minority of scientists maintains that the climate might respond to human-induced changes with a negative feedback, thereby stabilising climate. This group understands the facts but operates in a different part of the uncertainty envelope as compared to the majority of



climate scientists.

The sceptics who pounced on flaws in the IPCC's fourth assessment report span the full spectrum of society, including scientists (sometimes from fields such as physics, engineering and meteorology), corporations and members of the public. Ostensibly some of them put much effort in scouring through publications and poring over graphs to point out inconsistencies, lacunae and flaws. One has even conducted a field campaign to uncover the urban heat-island effect on instrumental records of temperature. All of this would suggest a commitment to ensuring transparency and rigour, and their openness to be convinced by new evidence.

In reality, though, these sceptics do not seem to be swayed by facts put forth to counter their arguments. Neither the IPCC's comprehensive assessments nor testimonies by respected scientists nor Al Gore's blitz have led to a change of heart. This suggests that many sceptics are not really worried about uncovering whether the planet's climate is changing as a result of human actions or natural variability. Their primary concern is to wage a relentless battle against those on the "other side". This approach thrives in nations where polarisation has come to form an integral part of the polity, most notably the United States and the United Kingdom. No wonder, then, that it is in these nations that the best-funded and most vociferous sceptics reside and operate.

In the polarised political climate of the US, for example, there are Republicans and Democrats, pro-life advocates and pro-choice advocates, and the gun lobby and gun-control pressure groups. Ultimately, though, these labels conform to one of two categories: liberalism and conservatism. Doing something about climate change has come to be seen as a liberal cause, perhaps because it may involve active government involvement and regulation, or perhaps because it is seen as against business. Therefore, as if by default, it must be opposed by conservatives. The liberals must then denounce this as just another way in which conservatives are undermining America. And on it goes.

The ultimate source of the most obdurate climate scepticism lies in a polarised worldview.

A cursory look at media reports on climate change – be it mistakes in the IPCC assessments or the leaked emails – suggests that the tone of the debate in the US and the UK is strikingly combative. Readers' comments on newspaper articles or on blogs are strongly polarised. What is remarkable is that not only are the details deemed contentious, the motivations of those who provide evidence for a human

Photograph courtesy of IISD/Earth Negotiations Bulletin

role in modern climate change are deemed malicious. There is a case to be made for terming these individuals as "climate-change deniers" instead of sceptics, but that might very well end up entrenching the polarisation that needs to be countered.

All of this is not to say that challenges to established science do not arise in other parts of the world. France has its own share of geoscientists denying anthropogenic climate change. But their motivations do not seem to be overtly related to the "liberal versus conservative" battle. And it was in India that the first doubts regarding IPCC's assessment of the melting of Himalayan glaciers were raised. India's environment minister discussed the Indian take on this issue in a concise and well-researched statement made during a press conference in Copenhagen. Neither the minister nor the mainstream Indian media, however, took these doubts to fundamentally question the human role in climate change.

The focus of the discussion needs to be fundamentally modified.

Because the ultimate source of the most persistent and obdurate climate scepticism lies in a polarised worldview, it is difficult to see how a relentless barrage of facts will, by itself, bring about a more constructive debate. As Daniel Sarewitz, an academic from the Consortium for Science, Policy and Outcomes at Arizona State University points out, "Science can decisively support policy only after fundamental political differences have been resolved."

A fresh approach

If the facts themselves are not sufficient then the focus of the discussion needs to be fundamentally modified. The discussion about climate change should not be allowed to become just another pawn in the battle between liberals and conservatives. Neither should it revolve around the binary question of "Do you believe in global warming?" The media has an important responsibility in this regard: outlets, particularly in the US and the UK, need to shift away from the polarised narrative that they so favour. Much of the world is more than comfortable with shades of grey. Indeed, in an increasingly globalised world where people have multiple and fluid identities, it would be difficult to imagine how such a narrative could work for much longer.

It is all very well for the Nordic countries to adopt stern environmental standards, but a change in US policies is absolutely essential to propel global action on climate change. Is there any possibility of changing the tone of the discussion away from polarisation? How can the scientific community, American and global, stimulate an informed discussion?

One way of achieving this would be to focus on global change as a multipronged challenge, avoiding a singular focus on global warming.

Photographs courtesy of IISD/Earth Negotiations Bulletin

Humans have modified and are modifying the planet in more ways than by warming the climate; many of these actions may directly or indirectly affect climate. The evidence base showing why people are calling for action to respond to those modifications may be less politically loaded and less amenable to attacks from sceptics. The economic costs of controlling vehicular pollution, for example, may be a source of debate between liberals and conservatives, but the need for doing so is not easy to trash. Similarly, the socioeconomic and biological impacts of ocean acidification may help bypass scepticism about global warming and coax relatively moderate policymakers to consider cutting carbon-dioxide emissions.

Many of the arguments against responding to climate change are economic – the costs of mitigation and the spectre of job losses provide much of the fodder for climate scepticism in the US. Climate scientists need to team up with economists and others to address such concerns and lay out the economic consequences of inaction. They also need to dispel the myth of the carbon-based economy being the cheapest alternative, for example, by calculating and highlighting the costs – monetary as well as geopolitical – of a reliance on oil. They need to sincerely engage policymakers from, and media outlets typically associated with, the "other" side to discuss how action on climate change could be supported without alienating the base.

Although determining what will work is not easy, what will not work is crystal clear: a semblance of arrogance and elitism. As pointed out by the author Bill McKibben, climate sceptics in the US have quite skilfully tapped into a section that is angry with those who they perceive to be elites. This is the same group of people who feel, rightly or wrongly, that science threatens their religious beliefs. They do not want to be preached to by scientists but may well be willing to listen to the pastors in their local churches. If facts are not enough, a sermon from the right individuals might create a willingness to listen. The global-change research community should not shirk from establishing a dialogue with religious leaders and convincing them of the need for action.

What will not work is crystal clear: a semblance of arrogance and elitism.

It is still a minority view, but there is growing recognition that more scientific evidence and better communication are necessary, but not sufficient, to induce action on tackling anthropogenic climate change: a change in the prevalent political discourse is needed. This is an exceedingly difficult task, but one that needs to be attempted if the need for action is as pressing as the global scientific community says it is. ▮

NINAD BONDRE is Science Editor at IGBP.

AFRICA'S RISKY GAMBLE

Well-managed plantations in Africa may, in principle, help mitigate the effects of a changing climate, both by boosting economies and providing alternative fuels. But as **Cheikh Mbow** points out, both the science and the politics underlying such an endeavour deserve closer scrutiny.

As Earth's climate continues to change, it is likely that the developing nations – many of which are in Africa – will bear the brunt of the consequences. Agricultural productivity, for example, could be affected substantially, putting the food security of such nations in jeopardy. At the same time, by participating in strategies to mitigate the effects of climate change, for example by contributing land to plantations that act as carbon sinks as well as biofuel sources, developing nations could earn much-needed ecosystem services or cash and contribute to the solution. Several African countries have large tracts of cultivable land, something that is at a premium in most developed nations. Millions of hectares of such land are now being leased on a long-term basis by nations as well as private corporations outside Africa. Ostensibly, this phenomenon could be viewed as a "new deal" being offered to the African continent: the cash from the leases could benefit local economies, whereas the plantations themselves will help sequester carbon or contribute to alternative energy. A closer look, however, reveals several potential problems with this perspective. The new deal could very well prove to be a risky gamble.

The majority of the world's reserve agricultural land is in Africa and South America.

Africa has large "unused" lands and cheap labour, compared with emerging economies (such as China and India) and oil-producing countries. As Figure 1 shows, the potential area for rainfed crops in Africa far exceeds the current area of arable land. A survey of studies cited in Cotula *et al.* (2009) suggests that the majority of the world's reserve agricultural land is in Africa and South America. Africa has thus become an attractive destination for the land-leasing business. In fact, some African countries – Egypt and Libya, for example – are themselves engaged in leasing land from other countries on the continent.

Of course, what constitutes available land is debatable; some of the land thus characterised may be used intermittently for grazing and shifting cultivation (Cotula *et al.*, 2009). The claims of vast tracts of available land in Africa may in some cases be exaggerated.

Although foreign corporations have been growing crops on African land for many years, what appears to be different today is the scale of the land rental business. A compilation from various sources (Table 1) suggests that Africa has leased at least 20 million hectares of its productive land during the past five years. Recently Ethiopia put 180,625 hectares of land on the rental market.

The carbon dimension

Given the amount of potential arable land in Africa (Figure 1), it is worth exploring the extent to which plantations could serve to sequester carbon, and thereby provide economic benefits to the continent's people. Recent work shows that dryland forests can sequester as much carbon as their counterparts in wetter regions (see page 7 of this issue); countries throughout Africa (and not just those in the tropics) could therefore undertake afforestation measures. Such

activities can be carried out under the auspices of the Clean Development Mechanism (CDM), which allows industrialised nations to buy credits from developing nations that engage in activities that help offset emissions.

However, a recent analysis (Mbow 2009) suggests that even when the best price of carbon in the international market is considered, an individual three-decade-old tree from a savannah ecosystem would be worth only four USD. This is far less than the value that would accrue from the services – firewood, fruits and medicines – that the tree could provide to its local population. But unless the monetary incentives to use African land for carbon sequestration are substantial and stable, it is difficult to see how local populations can be encouraged to invest in plantations and sustainable land-use. Indeed, there is little evidence for land acquisitions overtly motivated by the carbon market (Cotula *et al.*, 2009).

Many nations are contemplating a shift towards biofuels, a trend that has as much to do with securing long-term supplies of fuel as it has to do with reducing greenhouse-gas emissions. The European Union, for example, has set itself a target of using 10 percent biofuels by 2020. Such fuels can be produced from several plants, including maize, oil palm (*Elaeis guineensis*) and *Jatropha curcas* seeds. Although it is generally agreed that large areas of land will be required to satisfy the global biofuel demand, the estimates vary substantially.

An individual three-decade-old tree from a savannah ecosystem would be worth only four USD.

Based on the projected growth of biofuels until 2030, the International Energy Agency (IEA 2006) estimates that over 30 million of hectares of land will be needed. But calculations by Field *et al.* (2008) suggest that achieving even modest greenhouse-gas reductions by the year 2050 would entail bringing 1500 million hectares of land under cultivation of biofuel crops: this is equivalent to the total area currently under cultivation globally. This estimate is in agreement with that of Melillo *et al.* (2009), whose calculations show that biofuel crops would be grown on 1600-2000 million hectares by the year 2100, assuming that most fuel demand would be met by

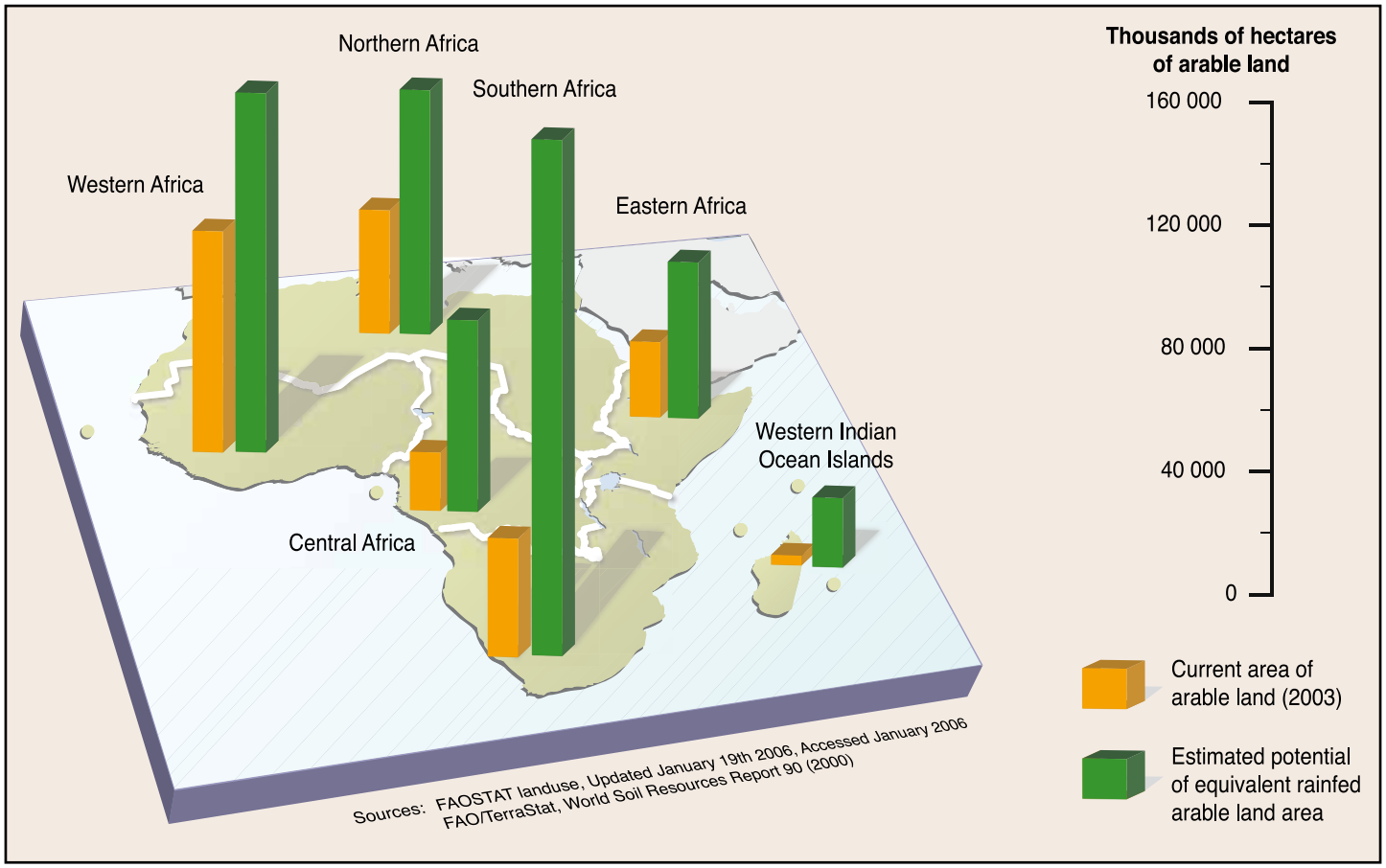


Figure 1. Africa has large reserves of land that is potentially available for rainfed agriculture. In principle, there is considerable scope for expansion of agriculture. As mentioned in the text, however, some of the land characterised as available may in fact be under use for grazing or shifting agriculture. Sources: FAOSTAT, FAO Terrastat. Original graphic on http://maps.grida.no/go/graphic/current_and_potential_arable_land_use_in_africa

biofuels by this time. Of course, many assumptions go into such calculations, and there is always a possibility that similar to other commodities in the past the biofuels bubble will burst some time in the future.

Few countries have the requisite "spare" land to devote to increasing crop production for biofuels, including the current leading producers such as the United States. Approximately 300 million hectares of potentially cultivable land is estimated for Africa (for example, Figure 1), and the continent is thus fast becoming one of the favoured destinations. Melillo *et al.* (2009) show that a switch to biofuels over the coming century would entail major land-use and land-cover changes. Most of these changes would occur in the tropical and subtropical regions of Africa and South America. And much of the growth in land area under biofuel crops would come at the expense of forests and pasture. This means that not only is the fertile cropland or the so-called fallow land in Africa a potential target, but its forests may also face severe pressure in the future.

Apart from the issues relating to local land access and food security, there is the broader question of whether afforestation and the reliance on biofuels will have tangible mitigation benefits. The analysis by Melillo *et al.* (2009), for example, points to substantial greenhouse-gas emissions due to the land-use changes and fertiliser input associated with increasing biofuel production. These authors suggest that forest preservation and careful management of fertilisers will be needed to reduce emissions associated with biofuels.

Growing plants to be used as raw material for biofuel production could be an attractive proposition for Africa if it triggered innovation in agriculture, created employment opportunities and ultimately helped reduce poverty. However, as pointed out by Cotula *et al.* (2009), such benefits depend critically on how equitable and just the enterprise is. The collusion of commercial and political interests may lead to loss of access to land and its resources by the poor and powerless. Given that Africa's CO_2 emissions over the past century have been negligible, it cannot be asked to play the role of the world's CO_2 tank without being offered real benefits. A deal needs to be profitable to the continent, besides facilitating long-term sustainable development.

Is the gamble worth it?

The land lease deals are contradictory with the new orientation of land-tenure rights in Africa. Since the 1990s, most African countries went into the new era of decentralisation, with a land ruling system that focuses on local communities. The evolution of the Senegal land tenure law – from colonial ownership to nationalisation to community transfer – is a clear illustration of the long history of land rights. The land-leasing business threatens to destabilise this progress because the control over natural resources tends to move back to national governments and large private corporations. It thus needs to be critically evaluated.

Current state policies for agriculture development and food security hold some important lessons in terms of what happens when resources are nationalised. For example, some governments have created national companies to produce rice (Senegal River, Mali in Niger River) or other cash crops such as cotton (Burkina Faso, Mali and Senegal), cocoa and palm oil (Ghana, Côte d'Ivoire). The stated purpose for setting these institutions up is to stimulate a

Cheikh Mbow

Figure 2. Land preparation for Arabic gum plantation. Project ASYLIA-GUM from Saudi Arabia in Dahra Village, north of Senegal.

Country leasing the land	Country offering land	Aim and magnitude of project
Bahrain	Sudan	Food crops
Bahrain	Egypt	Food crops
China	Democratic Republic of the Congo	Biofuels, oil palm 2.8 million hectares
China	Zambia	*Jatropha curcas*, 2 million hectares
Egypt	Uganda	Wheat, corn 850,000 hectares
India	Ethiopia	USD 1.5 billions
Italy	Senegal	*Jatropha curcas*
Libya	Mali	Rice 100,000 hectares
Qatar	Kenya	40,000 hectares
Saudi Arabia	Ethiopia	Wheat and rice
Saudi Arabia	Senegal	Arabic gum
South Africa	Congo	Food crops, livestock 10 million hectares
South Korea	Madagascar	1.3 million hectares
South Korea	Sudan	690,000 hectares

Table 1. Sample of known agreements to lease land in Africa

Sources:
Cotula *et al.* (2009); Laishley 2009;

http://makewealthhistory.org/2009/06/03/africas-land-deals-outsourcing-or-colonialism/;

http://www.panafa.net/blog/?page_id=417)

"green revolution" in the most productive lands of the country. However, the achievements of these companies after three decades of performance are rather limited. An analysis and reorientation of such initiatives must be performed before inviting external players to use the country's productive lands.

The land-lease business may be able to generate equitable development if strong governmental policies and actions ensure that crop production for biofuels does not compromise food security and that foreign corporations respect local land rights. For example, it could be made mandatory for the international lessees to sell a proportion of the crops they produce to local communities at local rates. And the international community could take committed action to guarantee stable and appropriate prices for carbon. For example, the Environmental Audit Committee of the UK House of Commons recently recommended that the government look into bolstering the price of carbon when it is particularly low (see the full report on http://www.publications.parliament.uk/pa/cm200910/cmselect/cmenvaud/290/29002.htm).

There is urgent need for a comprehensive analysis of the costs and benefits.

There is urgent need for a comprehensive analysis of the costs and benefits of inviting foreign nations and corporations to lease lands in Africa (Cotula *et al.*, 2009; Laishley 2009). Key issues pertain to the social and economic risks associated with land "expropriation" from local populations, the prospects for sustainable food security, accountability and impacts on local governance, and the potential environmental impacts. Only after such an analysis will it be possible to determine whether the risk is worth taking and the gamble will pay off. ▮

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GLOBAL CHANGE

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Megacities in the coastal zone

Nitrogen and climate

Earth-system impacts from changes in the cryosphere

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

The role of land cover and land use in modulating climate

Aerosols in the Earth system

Atmospheric pollution and climate

Acting on adaptation to global environmental change

ICSU's global-environmental-change programmes

DIVERSITAS – an international programme of biodiversity science

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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.