Global Change

International Geosphere-Biosphere Programme

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GLOBAL CHANGE
IGBP International Geosphere-Biosphere Programme

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

ICSU International Council for Science

Contents

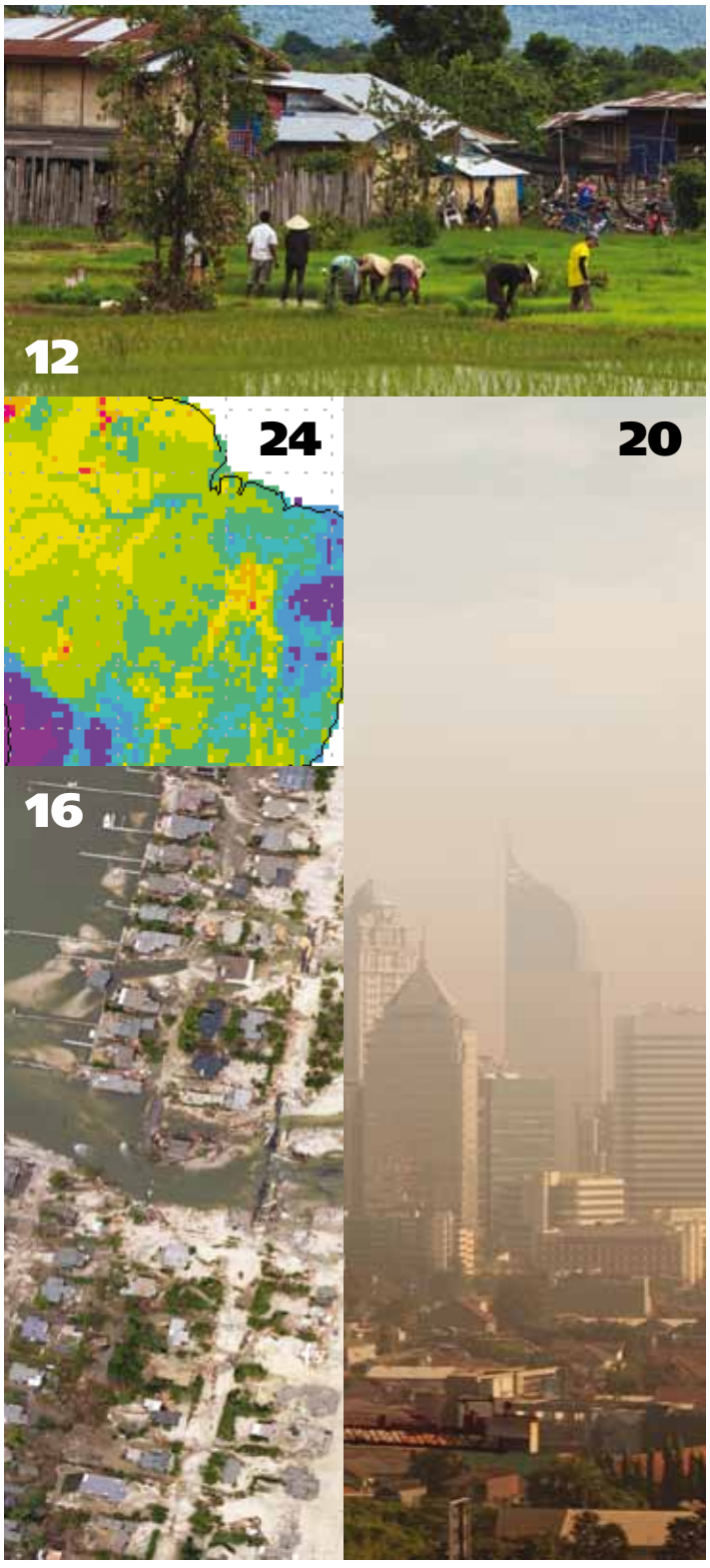
Cover image

Land is valuable and thus susceptible to coercive acquisition. Today's land grabs involve purchases or, more frequently, long-term leases in developing nations by international corporations. Common to the deals is the lack of transparency and disadvantaging of small landholders. See cover story on page 12.
Background image for cover illustration: ©iStockphoto.com/Andrew Penner

REGULARS

COVER STORY

FEATURES



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Editorial

Sybil Seitzinger, Executive Director, IGBP

December 2012 witnessed the formal dissolution of the Earth System Science Partnership (ESSP) in anticipation of the start of the Future Earth initiative. Set up by IGBP and the other three global-change programmes following the highly successful Amsterdam conference in 2001, ESSP aimed to facilitate an integrated look at the Earth system and promote greater interaction between the programmes. The continued collaboration among the programmes is a testimony to this legacy.

For over a decade, ESSP brought the programmes together via its joint projects, integrated regional studies and capacity-building activities. The joint projects addressed themes that cut across the remits of the individual global-change programmes: energy and the carbon cycle, food security, water resources and human health. The Global Environmental Change and Human Health (GECHH) project is finding its feet but the other projects have produced a substantial body of work.

The Global Carbon Project (GCP) takes a comprehensive look at both the biogeochemical and social aspects of the carbon cycle at a time when the climate effects of increasing atmospheric carbon dioxide are becoming ever more apparent. The project has not only coordinated international research into the carbon cycle but also synthesised it to provide novel perspectives. During the past few years, GCP's Global Carbon Budget (see page 6 of this issue) has become an invaluable resource for scientists, the media and the policy community.

The Global Water System Project (GWSP) focuses on the human modification of the water cycle and its impacts on societies and ecosystems. An important contribution of the project has been the creation of a digital water atlas, which provides online access to maps and datasets that clarify the complex interlinkages among the various components of the global water system. Project researchers also recently reviewed the global threats to human water security and biodiversity based on a global database of rivers.

The Global Environmental Change and Food Systems (GECAFS) project sought to understand the relationships between environmental change and food security by developing appropriate methodologies. Central to the project's work was the holistic concept of food systems, which accounts for not only food production but also its storage, delivery, pricing and consumption. One of the legacies of the project, which came to a close in 2011, is the creation of the Climate Change, Agriculture and Food Security (CCAFS) project.

Although ESSP has closed, its joint projects will continue to function during the transition to Future Earth under the guidance of the four global-change programmes. IGBP collaborates closely with the other global-change programmes and will continue to engage the joint projects. Moreover, IGBP's own activities continue to generate new scientific insights.

ESSP played an important coordinating function by collating the research of the global-change programmes and presenting it to various policy fora, most notably the Subsidiary Body on Scientific and Technological Advice (SBSTA). IGBP is now representing the programmes as their liaison with SBSTA.

ESSP was a bold attempt to bring together researchers that approached global environmental change from very different perspectives. An evaluation of the successes and failures of this attempt holds important lessons for new initiatives such as Future Earth.

> "For over a decade, ESSP brought the programmes together.

Future Earth

MOMENTUM is building for Future Earth, the new international ten-year research programme on global sustainability.

Future Earth received over 100 nominations for its Scientific Committee. About eight of the 16 or so committee members will be chosen from the Scientific Committees of the global-environmental-change (GEC) programmes including IGBP. An interim director will be announced shortly.

The final report from the Transition Team will be published soon. This report includes input from many stakeholders through regional workshops in 2012 and a workshop with core projects from the GECs. Further dialogues are planned for 2013.

The draft report highlights the crucial role of existing GEC projects to the success of Future Earth. Furthermore, it states national committees will "play a vital role in implementation of Future Earth at the national level".

The proposed research agenda identifies three themes: dynamic planet, global development and transformation towards sustainability.

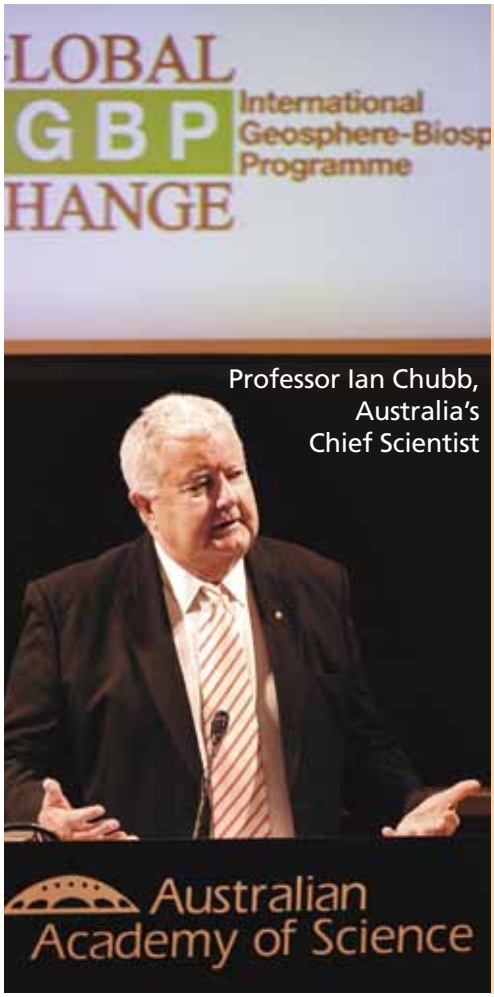
Paving the way for the new initiative, the influential Earth System Science Partnership (ESSP) ended in December 2012 (see editorial). ESSP's four projects will continue to be sponsored by the four GEC programmes.

In January, IGBP Chair James Syvitski and Executive Director Sybil Seitzinger met with other GEC programme chairs and directors to discuss the strategy for engagement with Future Earth.

Future Earth is currently being overseen by the Implementation Management Project Board. IGBP has two representatives on this eight-strong committee: IGBP Officer Jan Willem Erisman and LOICZ Executive Officer Hartwig Kremer.

IGBP's Owen Gaffney and ICSU's Head of Communications Denise Young have been working on a stakeholder analysis and development of the communications and engagement strategy.

A Future Earth website and social media sites will be launched soon.



Professor Ian Chubb, Australia's Chief Scientist

Mark Graham

TICKING TIME BOMBS IN THE EARTH SYSTEM

CANBERRA was the venue for Ticking Time Bombs in the Earth System, an IGBP-sponsored conference in November 2012. The two-day conference focused on four themes: the mismatch between scientific evidence relating to climate and policy responses; polar deglaciation and sea-level rise; multiple stressors on the Great Barrier Reef; and food security.

The event was organised by IGBP's Australian National Committee and hosted at the Australian Academy of Science. It coincided with IGBP's Officers' Meeting. IGBP Chair James Syvitski and Executive Director Sybil Seitzinger both spoke at the symposium, highlighting the work of the IGBP projects.

The event, which attracted Australia's leading scientists as well as policymakers and industry, was the second Australian Earth-system outlook conference. The leadership and support of Australian National Committee Chair Roger Gifford, Tas Van Ommen and Jeanette Mill and colleagues was instrumental in making this event an outstanding success.

The presentations from the symposium can be viewed here: http://science.org.au/natcoms/nc-ess.html

EVENTS

2013

May

21-24. Water in the Anthropocene conference. Global Water System Project. Bonn, Germany.

June

24-25. Society in the Anthropocene conference. Bristol, United Kingdom.

July

7-12. Radiation and Climate. Gordon Research Conference. New London, NH, USA.

August

23-2. September. 6th SOLAS Summer School. Xiamen, China.

September

9-11. Living Planet Symposium. European Space Agency. Edinburgh, United Kingdom.

23-25. Beijing Symposium on Global Change. Beijing, China.

27. Launch of IPCC AR5 WGI summary for policymakers. Stockholm, Sweden.

28. Public event associated with IPCC launch. Stockholm, Sweden.

26-29. 14th International River Symposium. Brisbane, Australia.

October

15-18. WCRP-ACPC Africa Climate Conference. Arusha, Tanzania.

November

4-7. International Conference on Regional Climate - CORDEX 2013. Brussels, Belgium.

18-22. 6th International Nitrogen Conference. Kampala, Uganda.

December

9-13. American Geophysical Union Fall Meeting. San Francisco, CA, USA.

NUTRIENT GLUT

A NEW report from the IGBP-sponsored International Nitrogen Initiative highlights how humans have massively altered the natural flows of nitrogen, phosphorus and other nutrients. These alterations have boosted food production and benefited energy production. But they have also led to water and air pollution that is damaging human health, causing toxic algal blooms, killing fish, threatening sensitive ecosystems and contributing to climate change.

Entitled *Our Nutrient World*, the report was launched at the United Nations Environment Programme (UNEP) Global Ministerial Environment Forum in Nairobi, Kenya, 18-22 February. It presents an assessment by nearly 50 experts from 14 countries that a 20% improvement in nutrient-use efficiency by 2020 would reduce the annual use of nitrogen fertiliser by 20 million tonnes. The researchers describe this goal as "20:20 for 2020".

The researchers' analysis shows how such increased efficiency could provide a net saving ranging from 46 to 400 billion US dollars per year. This figure includes implementation costs and financial benefits from reduced nitrogen use and improvements to the environment and human health. The report stops short of recommending global legislation to control nutrient use, but recognises that this is a global problem, especially given the global trade in agricultural products. It calls for an intergovernmental framework to address these issues, and proposes a road map of how such an agreement would look.

Lead author of the report, Mark Sutton from the UK's Centre for Ecology & Hydrology, said, "Our analysis shows that by improving the management of the flow of nutrients we can help protect the environment, climate and human health, while addressing food and energy security concerns."

Pollution sources considered in the report include emissions from agriculture and combustion of fossil fuel. Globally, around 80% of harvested nitrogen and phosphorus is consumed by livestock rather than directly by people, underscoring the links between meat consumption, global nutrient supply and pollution.

The report proposes a package of key actions to reduce these pollution threats, which include:

First, improve the management of nutrients in agriculture, including crops, livestock and manure management. Measures include a range of techniques which are already available, but typically not yet applied, including precision agricultural methods suitable for both developed and developing countries. One example already being used in Bangladesh is to "plant" large fertiliser pellets into the ground, preventing ammonia emission into the air.

Second, reduce nutrient losses from industry and wastewater treatment, including the recycling of available resources. A long-term ambition is identified to develop methods to recapture nitrogen oxides from combustion sources, which alone represents a lost resource worth around 39 billion dollars per year.

Third, improve local optimisation of nutrient flows, connecting arable and livestock farming to improve nutrient recycling opportunities.

Fourth, lower personal consumption of animal protein by voluntary reduction and avoiding excess, particularly in populations with diets dominated by meat. With rapidly increasing meat and dairy consumption, as Asia and Latin America aspire to European and North American norms, dietary choices have a huge potential to influence future levels of nutrient pollution.

Co-author Bruna Grizzetti, based at CNRS/Université Pierre et Marie Curie (UPMC) in Paris, France, said, "The option of localising agricultural production is a really important one. Crop and livestock farming are often separated by many hundreds of kilometres. Localisation helps improve nutrient recycling, reducing nutrient losses while bringing the production benefits and pollution responsibilities closer together."

www.initrogen.org

Sustainable development goals for people and planet

INTERNATIONAL goals for sustainable development must take a complex systems approach, argued researchers and analysts in a commentary published in *Nature* in March 2013.

The interdisciplinary group's commentary, *Sustainable Development Goals for People and Planet*, identified six goals that if met would contribute to global sustainability while helping to alleviate poverty. The goals are: lives and livelihoods, sustainable food security, secure sustainable water, universal clean energy, healthy and productive ecosystems, and governance.

The commentary coincided with several key meetings at the United Nations to discuss Sustainable Development Goals to follow on from the Millennium Development Goals due to end in 2015.

The researchers suggest that in the face of increasing pressure on the planet, adherence to traditional definitions of sustainable development threaten to reverse progress made in developing countries over past decades.

"Climate change and other global environmental threats will increasingly become serious barriers to further human development," said lead author Professor David Griggs from Monash University in Australia and former Vice-Chair of the World Climate Research Programme.

The team asserts that the classic model of sustainable development with three integrated pillars – economic, social and environmental – that has served nations and the UN for over a decade does not reflect reality.

"As population increases towards 9 billion people, sustainable development should be seen as an economy serving society within Earth's life support system, not three pillars," said co-author Dr Priya Shyamsundar from the South Asian Network for Development and Environmental Economics, Nepal, and an IGBP Scientific Committee member.

EMISSIONS GROWTH "WORRYING"

THE Global Carbon Project's (GCP) annual carbon budget reported that carbon dioxide emissions rose 3% in 2011. Global carbon-dioxide emissions show no sign of moving off the high-emissions trajectory. The gap between reality and the emissions trajectory required to keep global average-temperature increase below 2°C is expanding.

From 2000 to 2011, emissions grew on average 3.1% per year. Adhering to climate targets is now more likely to entail using technologies that remove carbon dioxide from the atmosphere – for example, carbon capture and storage connected to bioenergy.

"We are effectively relying on technologies that are yet to be fully developed and this leads to persistent uncertainties on how much they can contribute to future mitigation," said lead author of the study Glen Peters of CICERO, a climate research institute in Norway.

The study shows that global carbon-dioxide emissions in 2011 were 54% above 1990 levels. Most of the growth in emissions is from the so-called emerging economies. Chinese emissions grew 10% in 2011, or over 800 million tonnes of carbon dioxide, which is as much as Germany emits in one year. China is emitting almost as much per capita as the European Union, about 36% higher than the global average per capita emissions.

In 1990 developing countries accounted for 35% of global carbon-dioxide emissions, but in 2011 this was 58%. However, per capita emissions in developed countries continue to remain much higher than those in most developing countries.

"Each year of increased emissions makes a two-degree target harder to achieve. The only feasible way to keep below two degrees is for global reductions in emissions and this can only happen if the top emitters in the developed and developing world have deep and sustained mitigation," said Peters. "I am worried that the risks of dangerous climate change are too high on our current emissions trajectory," said co-author Corinne Le Quéré, Chair of GCP and Director of the Tyndall Centre for Climate Change Research. "We must reverse the trends in emissions before 2020," she added.

This research is based on the release of an extensive new dataset by the GCP. GCP is co- sponsored by IGBP.

Peters G *et al.* (2013) *Nature Climate Change* 3: 4-6.

Le Quéré C *et al.* (2012) *Earth System Science Data Discussions*, doi: 10.5194/essdd-5-1107-2012.

The Amazon gets a breather

SOME climate models may overestimate the risk of Amazon forest dieback due to carbon-dioxide-induced global warming, according to a study published in *Nature*.

Peter Cox of the University of Exeter and colleagues used a statistical relationship between a suite of climate-model outputs to estimate the sensitivity of tropical-land carbon loss to climate change. They estimate that tropical land will release 53±17 gigatonnes of carbon per kelvin, which is much lower than the projections of some models (over 150 gigatonnes of carbon per kelvin).

Cox P M *et al.* (2013) *Nature* 341–344, doi:10.1038/nature11882.

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Ocean-atmosphere interactions

A RECENT review published in *Environmental Chemistry* highlights emerging issues in ocean-atmosphere exchange and discusses the research strategies that will be deployed to deepen our understanding. The issues include: upwellings and associated oxygen minimum zones; sea ice; marine aerosols; atmospheric nutrient supply; and ship emissions.

The review was commissioned by the Surface Ocean-Lower Atmosphere Study (SOLAS) project co-sponsored by IGBP. Since its inception in 2004, the project has implemented its science plan to coordinate international research on the biogeochemical and physical exchanges across the ocean-atmosphere interface. The review – the project's mid-term strategy – responded to a growing realisation that emerging scientific challenges warranted a re-evaluation of the project's aims and research strategies.

Law C S *et al.* (2013) *Environmental Chemistry* 10: 1-16.

BEYOND CITY LIMITS

HUMANITY is on course to build more urban areas during the first 30 years of this century than all of history combined. According to some projections, the total urban area is expected to triple between 2000 and 2030, while urban population is expected to increase to almost 5 billion.

"On this kind of trajectory, an area the size of 15,000 FIFA-accredited football fields will become urban every day during the first three decades of the 21st century," says Karen Seto, an urbanisation expert from Yale University.

Seto is co-author of a recent paper published in the journal *AMBIO*, the result of IGBP's 2011 planetary stewardship workshop.

The paper, *Planetary stewardship in an urbanising world: beyond city limits,* argues for broadening the concept of urban sustainability to account for the global flow of goods and materials into urban areas. Because urban areas drive much of the global changes we see, whether in energy use, food supply, resource depletion or land-use change, looking at the sustainability of individual cities is of limited value.

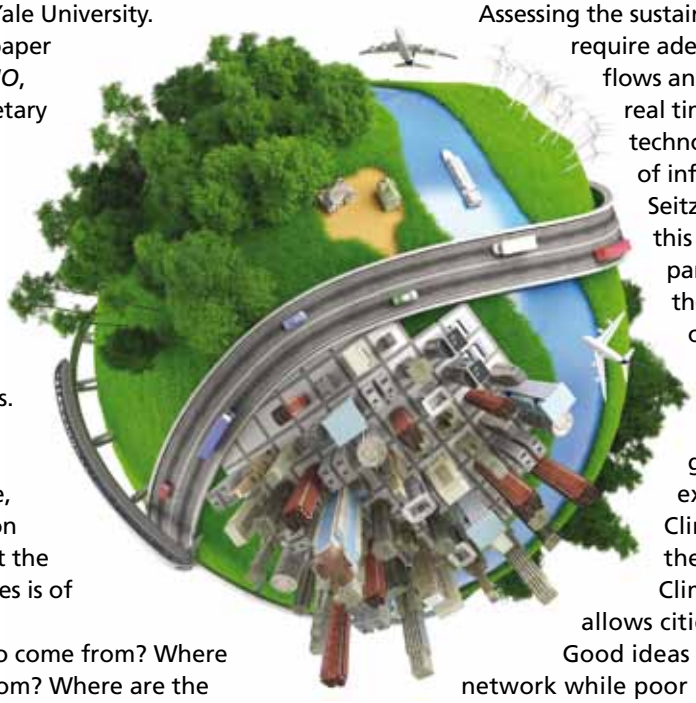


Illustration: iStockphoto.com/Pablo Scapinachis

"Where is the food going to come from? Where is the water going to come from? Where are the minerals, the fibre, the wood?" asked lead author and IGBP Director Sybil Seitzinger in an interview in Reuters AlertNet.

Many cities are now developing strategies to reduce pollution and congestion, improve the quality of life of their citizens and respond to growing concern about human impact on climate and the environment. But such initiatives often ignore the environmental footprint from global flows of goods and services such as food, water and energy to cities: sustainability, it seems, stops at the city limits.

The paper states: "The sustainability of a city can no longer be thought of in isolation from the combined resource use and impacts of cities globally." Instead, the team proposes that cities analyse how resources consumed within a city are sourced, produced and transported. One solution could be to view sustainable urbanisation from the perspective of a system of cities. A feature of such a system would be an awareness of the global resource use of cities combined. The benefits of a network of this kind could be twofold, contributing to "planetary stewardship" whilst providing long-term resource security for cities.

Assessing the sustainability of a system of cities will require adequate information on resource flows and their impacts, preferably in near real time and on a global scale. "Digital technologies are now putting this kind of information within our grasp," said Seitzinger. But she argues that even this is not enough. Cities could form partnerships with non-urban areas, the farmlands, coastal zones and other regions.

Recently, cities across the globe have joined forces in alliances to curb greenhouse-gas emissions, for example, through the C40 Cities Climate Leadership Group and the World Mayor's Council for Climate Change. This approach allows cities to learn from one another. Good ideas can spread through the network while poor ideas can be ditched quickly.

However, these efforts may not focus explicitly on non-urban regions that often provide resources to urban areas. The notion discussed in the paper of a partnership between cities and between cities and non-urban regions is novel but untested. This new approach could harness existing partnerships and provide the foundations for a more sustainable approach to urbanisation and urban living this century.

These ideas resulted from a three-day international workshop on planetary stewardship organised by IGBP at the Royal Swedish Academy of Sciences, 13-15 June 2011.

Seitzinger S P *et al.* (2012) *AMBIO* 41(8): 787-794.

Business leaders to set global sustainability targets

THE WORLD Business Council for Sustainable Development (WBCSD), a CEO-led organisation representing nearly 10% of the global economy, is seeking advice from researchers on sustainability targets for businesses.

WBCSD has enlisted help from the Stockholm Resilience Centre (SRC) to turn the council's *Vision 2050* report, published in 2010, into action on the ground with targets set for 2020 – *From Vision 2050 to Action 2020*. SRC Director Johan Rockström, together with Will Steffen and Katherine Richardson, began this dialogue with WBCSD in late 2012. SRC is coordinating international input from the research community.

"We are applying the 'planetary boundaries' concept as our starting point because it highlights the need to hold multiple global issues in mind simultaneously, recognising that their dynamic interactions also matter for sustainability," says Gail Whiteman, a sustainability and climate change academic at Erasmus University, Rotterdam, and Professor-in-Residence at WBCSD. The concept also helps identify the most urgent priorities, she added.

"We need to set realistic targets for businesses that push them to reduce greenhouse gases, protect vital ecosystem services, and improve efficiency of nitrogen and phosphorus use," she said.

The organisers stress that the scientific legitimacy and authority of *From Vision 2050 to Action 2020* is crucial. Expert opinion is being sought. Covering a broad range of scientific issues in global sustainability, WBCSD plans to have a draft ready for circulation in March, and scientific input open until September 2013.

IGBP secretariat staff have attended two of the initial meetings with WBCSD in Stockholm.

Karen Smyth, IGBP's Deputy Director of Social Sciences, said, "This is a positive step from the business community and it is encouraging to see that WBCSD wishes to address social, as well as biophysical conditions. We want to encourage our community to engage in the debate and help develop robust targets for business."

The WBCSD includes some of the world's largest companies including Unilever, Nestlé, Toyota, Sony, Dow Chemicals, General Electric, Chevron, Procter & Gamble and Coca-Cola.

For more information, contact Sarah Cornell at SRC (sarah.cornell@stockholmresilience.su.se) or Gail Whiteman, Professor-in-Residence at WBCSD (whiteman@wbcsd.org)

MILANKOVITCH THEORY ON FIRM GROUND

Dan Costa

A RECENT modelling study published in *Nature* confirms that climate change in the Southern Hemisphere (SH) during the last deglaciation was triggered by warming in the Northern Hemisphere (NH). It thus provides strong support for the Milankovitch theory, which posits that orbitally induced summer-insolation changes in the NH drive climate change in the SH.

Palaeoclimate data show that warming in the SH, during the last deglaciation beginning 22,000 years ago, was synchronous with or slightly preceded that in the NH. This observation has been difficult to reconcile with the Milankovitch theory, suggesting that either (a) the NH signal was transmitted to the SH or (b) summer insolation changes in the SH more or less matched those in the NH (or were amplified by sea-ice effects). Analysis of the data themselves cannot confirm one or the other possibility.

To overcome this limitation, Feng He of the University of Wisconsin-Maddison and colleagues turned to a coupled atmosphere-ocean general circulation model. They ran simulations to evaluate the effect of four different forcings on temperatures in the two hemispheres: orbital changes, atmospheric carbon-dioxide concentration, ice sheets and the Atlantic meridional overturning circulation (AMOC). They also compared model results with temperature estimated from palaeoclimate data for the SH.

The researchers found that orbital forcing by itself is sufficient to explain significant NH warming at the onset of deglaciation; the SH in contrast shows little warming. The resultant retreat of NH ice sheets probably led to a significant decline in the AMOC beginning around 19,000 years ago. Indeed, the simulation forced solely by changes in this variable captures much of the temperature change in the SH.

Greenhouse-gas concentrations respond to Southern Ocean processes and Antarctic temperature. The simulations in this study support the argument that the increase in carbon-dioxide concentrations beginning 17,000 or so years ago – and the resultant greenhouse warming – were responsible for global deglaciation.

Feng H *et al.* (2013) *Nature* 494: 81-85, doi: 10.1038/nature11822.

BLACK CARBON: GLOBAL ASSESSMENT

IN JANUARY, Beijing made headlines worldwide when air pollution reached unbearable levels. Burning more coal to combat freezing temperatures is a likely cause of the pollution. A temperature inversion and other weather conditions caused the soot – or black carbon – to hang around the city.

Coincidentally, on 15 January IGBP's International Global Atmospheric Composition (IGAC) project published a landmark study on the effects of black carbon on climate in the *Journal of Geophysical Research: Atmospheres*. The report – the first comprehensive analysis of this issue – also generated headlines worldwide, appearing on the *BBC,* and in *The Economist, The New York Times, The Times of India, Reuters* and *The China Post*. Indeed, the report led to over 100 news stories in the world's leading media, many connecting it to city pollution.

The 232-page open-access report backs recent research proposing that black carbon is the second largest human contributor to global warming and its influence on climate has been greatly underestimated.

It says the direct influence of black carbon on warming the climate could be about twice previous estimates. Accounting for all of the ways it can affect climate, black carbon is believed to have a warming effect of about 1.1 Watts per square metre (W/m²), approximately two thirds of the effect of carbon dioxide – the largest human contributor to global warming.

Co-lead author David Fahey from the US National Oceanic and Atmospheric Administration (NOAA) said, "This study confirms and goes beyond other research that suggested black carbon has a strong warming effect on climate, just ahead of methane."

The study, a four-year effort, is likely to guide research efforts, climate modelling and policy for years to come.

The report's best estimate of direct climate influence by black carbon is about a factor of two higher than most previous work. This includes the estimates in the last Intergovernmental Panel on Climate Change (IPCC) assessment released in 2007, which were based on the best available evidence and analysis at that time.

The results indicate that there may be a greater potential to curb warming by reducing black-carbon emissions than previously thought.

"There are exciting opportunities to cool climate by reducing soot emissions but it is not straightforward. Reducing emissions from diesel engines and domestic wood and coal fires is a no brainer, as there are tandem health and climate benefits. If we did everything we could to reduce these emissions we could buy ourselves up to half-a-degree less warming – or a couple of decades of respite," says co-author Professor Piers Forster from the University of Leeds' School of Earth and Environment.

The international team urges caution because the role of black carbon in climate change is complex. "Black carbon influences climate in many ways, both directly and indirectly, and all of these effects must be considered jointly," says co-lead author Sarah Doherty of the University of Washington, an expert in snow measurements. The dark particles absorb incoming and scattered heat from the sun (solar radiation); they can promote the formation of clouds that can have either a cooling or warming effect. And black carbon can fall on the surface of snow and ice, promoting warming and increasing melting. In addition, many sources of black carbon also emit other particles that have a cooling effect and thus serve to counteract the warming caused by black carbon.

The research team quantified all the complexities of black carbon and the impacts of co-emitted pollutants for different sources, taking into account uncertainties in measurements and calculations. The study suggests mitigation of black-carbon emissions must consider all emissions from each source and their complex influences on climate. Based on the analysis, reductions in black carbon targeting diesel engines followed by some types of small household stoves that burn wood and coal would have an immediate cooling impact.

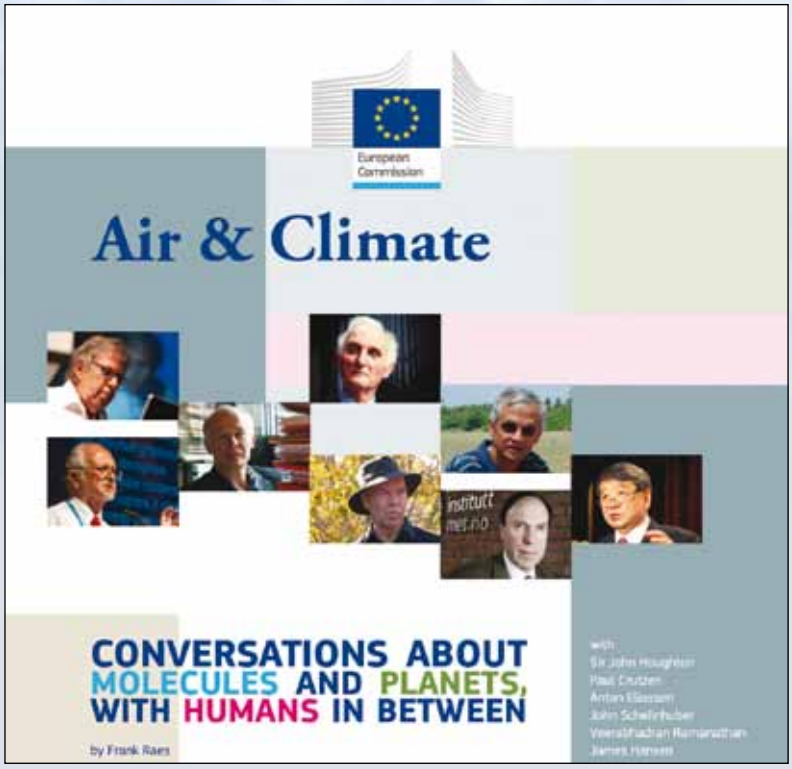
In addition, the report finds that black carbon is a significant cause of the rapid warming in the Northern Hemisphere at mid to high latitudes, including the northern United States, Canada, northern Europe and northern Asia. This demonstrates that curbing black-carbon emissions could address regional climate change while having a positive impact on human health.

"Policymakers, like the Climate and Clean Air Coalition, are talking about ways to slow global warming by reducing black-carbon emissions. This study shows that this is a viable option for some black-carbon sources and, since black carbon is short lived, the impacts would be noticed immediately. Mitigating black carbon is good for curbing short-term climate change, but to really solve the long-term climate problem, carbon dioxide emissions must also be reduced," says co-lead author Tami Bond from the University of Illinois at Urbana-Champaign.

Bond T *et al.* (2013) *Journal of Geophysical Research: Atmospheres,* doi:10.1002/jgrd.50171. http://onlinelibrary.wiley.com/doi/10.1002/jgrd.50171/abstract

Book Review

BLUE SKIES: A HOMAGE TO FUNDAMENTAL RESEARCH



FROM the ozone hole to acid rain, in the last 40 years the sky really was the limit for major scientific breakthroughs in atmospheric research. A small handful of scientists played pivotal roles in many of the major discoveries. Now their stories have come together in one volume written by Frank Raes.

Raes' book, *Air & Climate: Conversations about molecules and planets, with humans in between*, captures a series of interviews with some of the world's most influential atmospheric researchers. Between 2009 and 2011, in quiet moments snatched between talks at science conferences and en route to airports, Raes recorded candid conversations with Paul Crutzen, James Hansen, Mario Molina, Sir John Houghton, John Schellnhuber, Veerabhadran Ramanathan, Anton Eliassen and C S Kiang.

Each academic tells his own remarkable story, from early upbringing to major discoveries, Nobel prizes and life in the policy and media spotlights.

These are the people who linked CFCs to stratospheric ozone destruction, who grasped the full implications of climate change, identified greenhouse gases beyond carbon dioxide and tracked long-range pollutants. From their work emerged the new discipline of Earth-system science. Paul Crutzen and John Schellnhuber were members of IGBP's Scientific Committee and had a profound influence on its direction.

Raes explained, "At a certain moment I realised I was in contact with all these people and that they inspired me. Inspired, not about how to tackle specific issues in our research, but more about how to be a responsible scientist, standing with both feet within society. I wanted to share that inspiration."

Some common threads emerge from the book, published by the Joint Research Centre (JRC) of the European Commission where Raes is Head of the Climate Risk Management Unit. For example, Swedish academic Bert Bolin appears several times. Bolin, who died in 2007, was a major figure in international research and is often credited with spearheading the Intergovernmental Panel on Climate Change (IPCC), the World Climate Research Programme and IGBP.

Another common theme was the difficulty breaking through the barrier between science and society, though the rewards for some were substantial. Sir John Houghton, Chair of IPCC Working Group One (1988-2002), described it as one of the greatest experiences of his life. But all interviewees faced frustration at the difficulties convincing the world to sit up and listen. How do you explain that "invisible gases are attacking an invisible layer high up in the atmosphere that shields us from invisible rays," opined Mario Molina.

Raes' book gives a brief glimpse into the creative minds of the greatest scientists; people who can persist with problems long after everyone else has packed up and gone home. Paul Crutzen remarked that you need "total concentration on the subject. You wake up and go to bed thinking about it. Early morning hours can be especially productive."

Few of the researchers had any inkling their research would be particularly relevant to society at the beginning of their journey. But once they realised, they felt there was no other way than reaching out until their findings became common knowledge. This wonderful book shows time and time again the unexpected value – to our entire civilisation – of basic research in environmental sciences. As the global – change programmes morph into Future Earth – a programme focusing on solutions – this message comes at an important time.

The book can be downloaded from the JRC website (Google the title and author). Hard copies are freely available while stocks last. Email JRC-H07-SEC@ec.europa.eu.

OWEN GAFFNEY

New deputy director appointed

DR KAREN SMYTH has joined IGBP as Deputy Director of Social Sciences. Smyth is a social scientist who joined IGBP in 2011 to help coordinate Planet Under Pressure. Previously, Smyth led the Rural Society Research team within the Land Economy and Environment research group at Scotland's Rural University College (www.sruc.ac.uk/). As a senior lobbyist, she was also heavily involved in environmental and agricultural policy development in the UK and Europe. She will promote stronger ties between the traditional IGBP community and the social-science community as we move into Future Earth.

IPCC report to be launched in Stockholm

ON 27 SEPTEMBER 2013, all eyes will be on Stockholm when the Intergovernmental Panel on Climate Change (IPCC) releases the first part of its Fifth Assessment Report. IGBP is working with IPCC on a series of public and policy briefings in the city.

The Working Group One report, chaired by Thomas Stocker (former Chair of IGBP's Past Global Changes project) and former IGBP Scientific Committee member Qin Dahe, assesses the "physical scientific aspects of the climate system and climate change".

IPCC was created in 1988 by a team of scientists led by Swedish atmospheric physicist Bert Bolin. Bolin had set up IGBP, which has its secretariat in Stockholm, the previous year.

Since the previous IPCC report released in 2007 and its recognition by the Nobel Committee, the organisation has come under fire from climate sceptics and a section of the media intent on challenging the credibility of the panel. In response, the IPCC has reviewed procedures to reduce errors and appointed a new head of communications, former Reuters correspondent Jonathan Lynn, to improve interactions with the media.

Earth System Science Partnership dissolves

FOR A DECADE, the Earth System Science Partnership (ESSP) has brought together the four global environmental change programmes, IGBP, DIVERSITAS, the International Human Dimensions Programme on Global Environmental Change and the World Climate Research Programme. As part of the transition to Future Earth, ESSP formally dissolved on 31 December 2012.

For many years ESSP has been led by leaders in the field of Earth-system science. Rik Leemans, Martin Rice and Ada Ignaciuk created a strong partnership and oversaw the development of some of the most influential interdisciplinary research projects in recent years, including the Global Carbon Project, which produces the influential global carbon budget, and the Global Water System Project. All existing projects will continue in the interim and will be sponsored directly by the global-change programmes, including IGBP. The programmes will also continue their close collaboration.

Rik Leemans and Martin Rice continue to play active roles in the formation of Future Earth.

STRESSED OCEANS IN THE SPOTLIGHT

OCEAN acidification is already affecting oyster hatcheries on the US West Coast, according to findings reported at an international symposium late last year.

Convened by IGBP, the Scientific Committee on Oceanic Research and the UN's Intergovernmental Oceanographic Commission, the Third Symposium on the Ocean in a High-CO_2 World attracted 540 researchers from 37 countries. The event was chaired by Ulf Riebesell from German research institute GEOMAR.

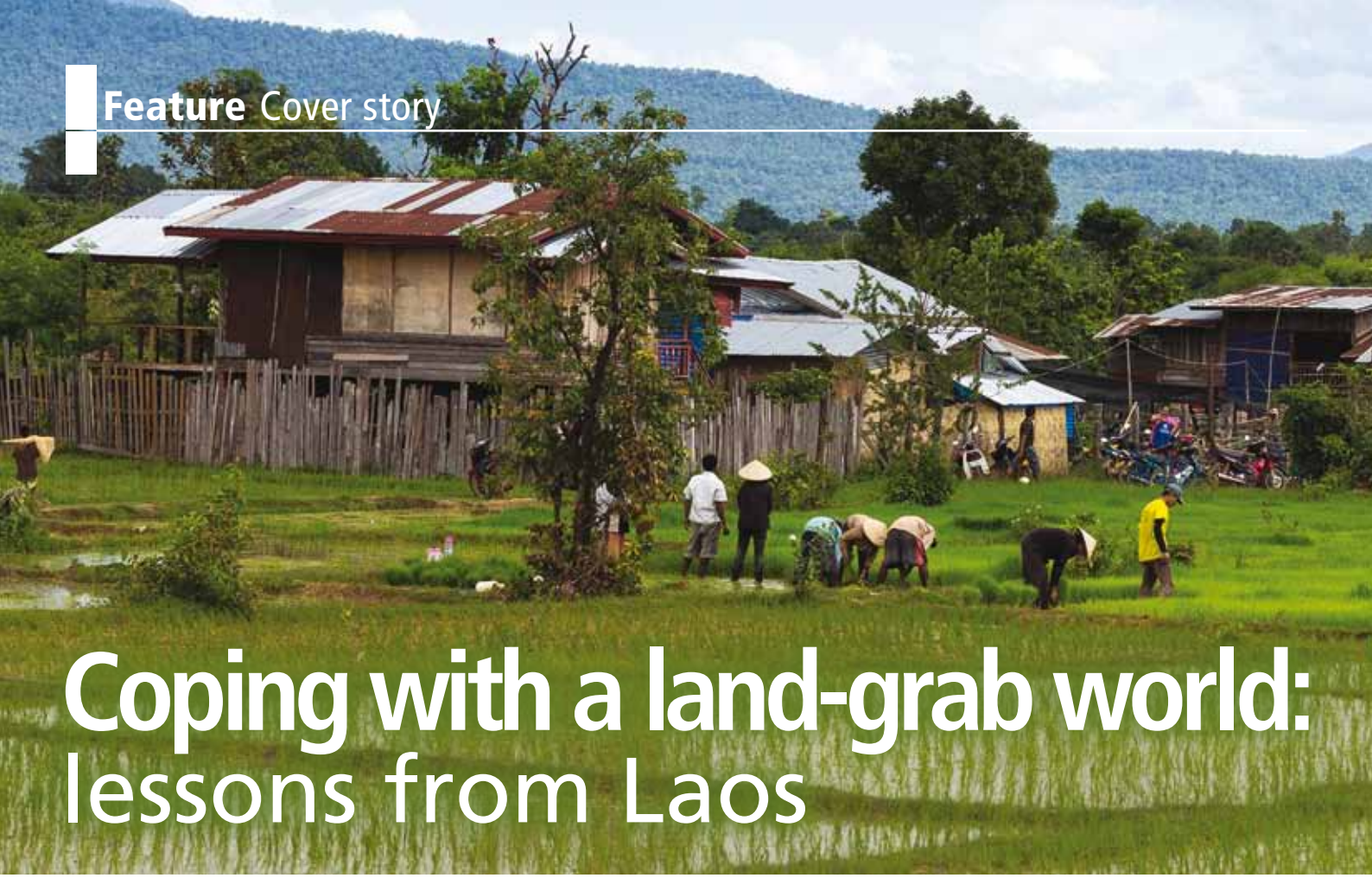
The symposium held a policy day led by Prince Albert of Monaco and former NOAA chief Jane Lubchenco, with participants from the US Congress, the shellfish industry, NGOs and the media. Over 30 journalists attended the symposium, leading to high-profile coverage in *Science*, *Nature*, *Scientific American*, *The Washington Post* and many more media. Marine scientist Joanie Kleypas from the Center for Global Dynamics in Colorado summarised the findings from the previous three days.

Delegates discussed the state of the oceans and the rate of change of ocean chemistry. Three key stressors on oceanic ecosystems were highlighted: ocean acidification, rising temperatures and de-oxygenation. Scientists report that while some organisms will struggle as ocean chemistry changes, there is evidence that others may adapt and thrive in these new conditions. Predicting how whole ecosystems will change in response to rising levels of CO_2 will be challenging, but we know that change is inevitable.

"A main theme coming through strongly was the multiple stressors on the oceans. This may be the focus of the next symposium," said IGBP Deputy Director Wendy Broadgate. Also discussed was the impact on aquaculture.

The economics of ocean acidification was higher on the agenda than previous symposia. Indeed, social scientists more generally were out in force, indicating this is a fertile area of research. But estimation of the economic and social costs of ocean acidification is in its infancy and prone to large uncertainties.

Following the symposium, Broadgate is coordinating a new ocean acidification summary for policymakers based on the outcomes of the event. The event was used to launch a new data visualisation on ocean acidification produced by Google, IGBP and the International Union for Conservation of Nature.



Coping with a land-grab world: lessons from Laos

In late 2012, Oxfam published a report entitled *Our Land, Our Lives: Time out on the global land rush*. Pointing to the deleterious consequences of large-scale land acquisitions in developing countries, Oxfam called on the World Bank to freeze its own land investments and review its policy and practice to prevent "land-grabbing". And earlier this year the Rights and Resources Initiative, in its 2012/2013 review, suggested that developing nations faced a stark choice: they could turn their rural citizens into landowners or landless labourers. These documents are only the latest in a series of reports and media articles on the topic of land grabs that have been published during the past few years. Clearly, the issue – which came to prominence in 2008 – is not simply a passing fad.

Despite the continuing attention, it has been challenging to acquire reliable data at the global scale (Cotula 2012). Existing estimates have relied on a combination of media stories and research reports (Friis and Reenberg 2010). The Land Matrix project – a partnership between several research institutions – is addressing this gap by systematically collating and verifying information on large-scale land acquisitions (Box 1). The Land Matrix is an online public database that permits all users to contribute to and improve data on land deals, and for this data to be visualised (http://landportal.info/landmatrix).

Global patterns of land acquisitions are important for the overview they provide. But acquiring quality data on a global scale is challenging and considerable limitations persist in terms of data sources, data quality and definitions used. Nevertheless, the growing evidence base of the Land Matrix allows the identification of broadly generalisable patterns. In contrast, local case studies entail more robust data and can yield insights into context-specific processes and outcomes. Yet, their results are difficult to generalise.

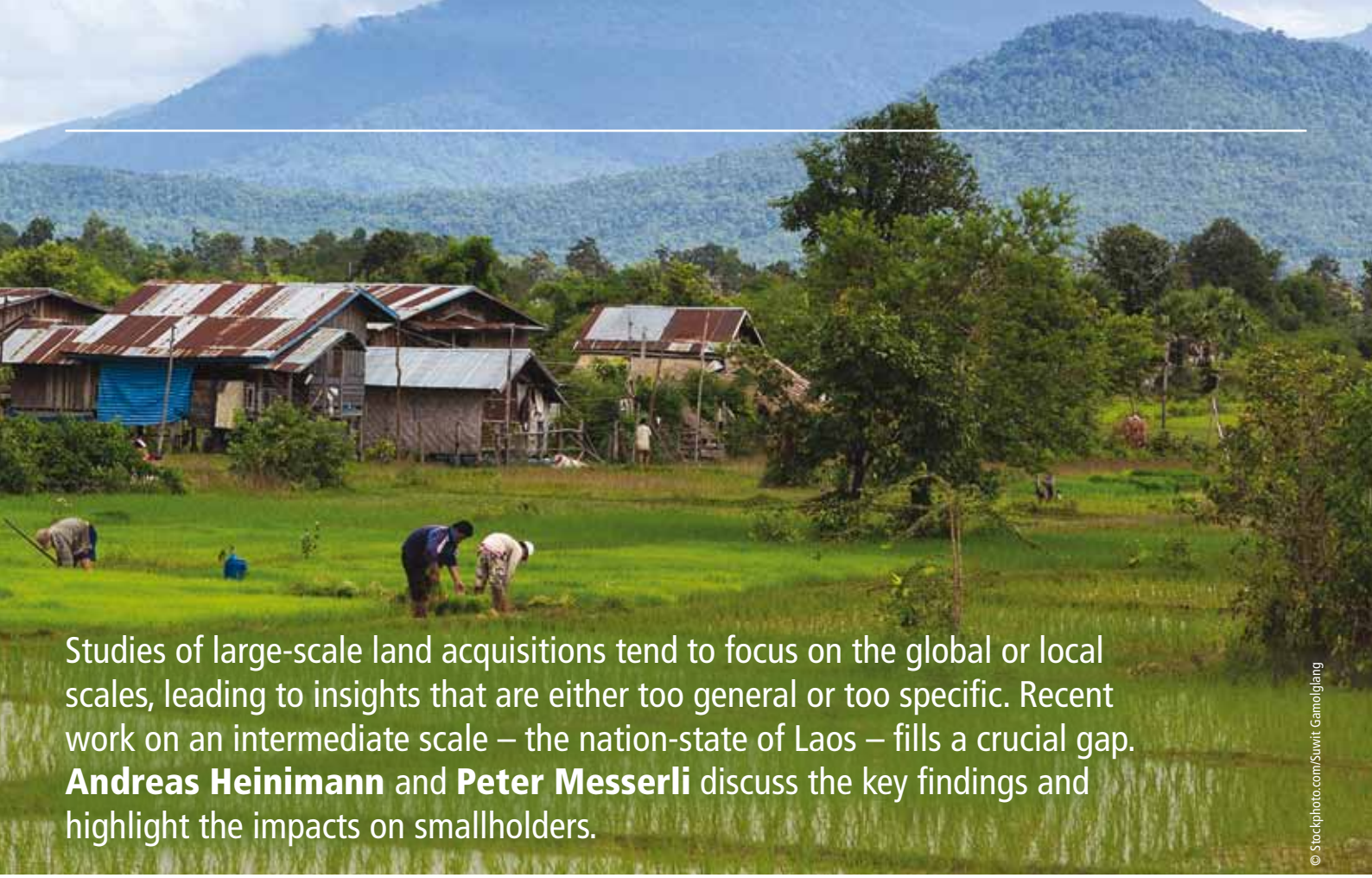
Few studies have focused on the middle ground – detailed and spatially explicit inventories of land deals that cover large areas (for example, entire nations). The Lao People's Democratic Republic (hereafter referred to as Laos; see Box 2) is a rare exception. Here, government agencies in collaboration (2007-2010) with the German Agency for International Cooperation (GIZ) carried out an inventory based on land-concession and land-lease agreements that were actually signed. In this article we first assess the global picture, relying primarily on the findings of Anseew *et al.* (2012), before zooming into Laos.

The global picture

The Land Matrix reveals reported land deals covering 83 million hectares (ha); these deals were initiated, negotiated or implemented over the period of 2000-2010. This confirms that the rush for agricultural land is real and represents neither media hype nor a short-term reaction to the food price spikes of 2008. Even if only half of these deals were to be confirmed they would amount to 5% of the available agricultural land in the most affected countries: 56.2 million ha in Africa, followed by Asia (17.7 million ha) and Latin America (7 million ha).

Most of the countries that have sold or leased land have agrarian economies and high rates of malnourishment. Small landholders dominate agriculture in such countries, but the institutional mechanisms to safeguard their rights tend to be weak. Indeed, numerous case studies around the globe show that governments are often selling or leasing land over which smallholders have customary user rights. Large shares of the land deals (45%) seem to be taking place predominantly in regions where small-scale agriculture is practised. This increases greatly the chances of intense competition for cropland with local communities.

The big players engaged in land deals are the Gulf States and the emerging economies such as China, India and Brazil. Deals made by such nations exceed those by the OECD countries. Strong intra-regional transactions exist



Studies of large-scale land acquisitions tend to focus on the global or local scales, leading to insights that are either too general or too specific. Recent work on an intermediate scale – the nation-state of Laos – fills a crucial gap. **Andreas Heinimann** and **Peter Messerli** discuss the key findings and highlight the impacts on smallholders.

and involve private and state-owned companies, investment funds and private-public partnerships. Less than a third of the investments target food production, the vast majority of which is exported. Moreover, investors are seeking flexibility by using the so-called flex-crops – such as sugar cane, soya and oil palm – that can be used for multiple purposes (25% of all investments). Plants not used for food – such as tree plantations, cotton and non-flex crops used to make biofuels – make up the rest of investments.

Zooming in on Laos

But what is happening at the national scale in the countries that sell or lease land? In 2012, the Centre for Development and Environment (CDE) of the University of Bern conducted an extensive analysis of land deals in Laos with the support of the Swiss government (SDC) (Schoenweger *et al.* 2012). This shows that the last decade has seen a dramatic expansion (over 50-fold in terms of project numbers) in the granting of land concessions and leases in Laos. Part of this has been driven by "open-door" policies aimed at attracting foreign direct investment as a means of achieving economic development objectives.

This analysis revealed 2600 land deals in Laos that cover 1.1 million ha, a figure that may pale in comparison with the immense land deals being sealed in Africa but is very significant in the context of Laos. It amounts to roughly 5% of the nation's land and is more than the total land used for the production of rice – the staple diet and the principal agricultural export of Laos. Clearly, these deals form some of the most significant land transformations in Laos' recent history. Interestingly, the Land Matrix points to only 49 deals covering an area of over 0.48 million ha for Laos. This vast underestimation underscores how global assessments tend to show only the tip of the iceberg, at least for some countries.

Foreign Direct Investment dominates the land leases (> 72% of all land granted). Vietnam, China and Thailand, all of which share extensive borders with Laos, are the major foreign investors, suggesting that proximity to Laos remains a major factor in investors' interest. Thai investments focus on the agriculture subsector, whereas Vietnam and China both hold much more land in mining and tree plantation projects. Because of the very limited capacity for value addition via processing in Laos, most of the products are exported to the investing countries in raw form.

Land deals occur in a range of economic sectors, but are overwhelmingly focused on the primary sector constituted mainly by mining, agriculture and tree plantations. 50% of the total land concession/leases granted involve mining (mainly copper and gold). Agriculture and tree plantation (mainly rubber and eucalyptus) cover a large share of the remaining area. A closer look at investments in the agriculture and

Box 1. On land deals

Large-scale investments in land often involve transnational companies backed by financial investors. These companies seek to secure access to land in developing countries to produce food and non-agricultural commodities as well as biofuels. Land may be purchased, but more often investors are granted long-term leases on government-owned land. Such land transactions are commonly referred to as land-grabs when they lack transparency, violate human rights, lack the participation and prior and informed consent of land users, and do not take into consideration social and environmental impact assessments. These criteria are summarised in Oxfam (2012) and further information can be found in the Tirana Declaration of the International Land Coalition. www.landcoalition.org/about-us/aom2011/tirana-declaration.

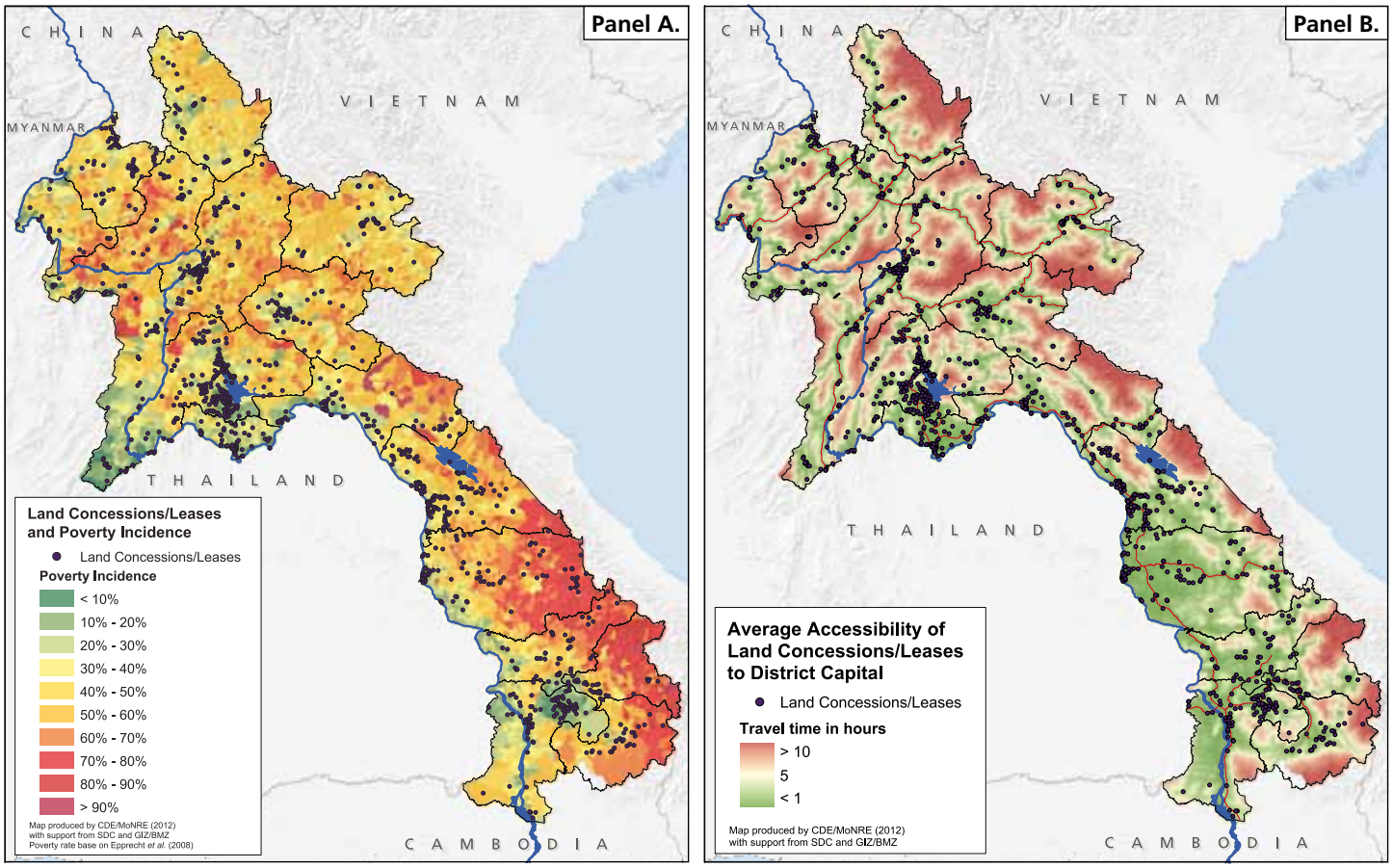


Figure 1. Investments in Laos with respect to poverty incidence (Panel A) and accessibility (Panel B). The maps show that the poorest and most remote areas benefit far less from the investments accompanying land deals than better-off and more accessible areas. Contrary to what is sometimes claimed, this suggests that investment in land neither prioritises nor is able to successfully address the issues of rural poverty alleviation or infrastructure development in marginal areas.

plantation subsectors suggests that a substantial transition in agricultural production is under way. In contrast to the traditional emphasis on rice, subsistence crops and a diverse range of cash crops and forest products, there is now a strong focus on a very limited diversity of export-oriented products. The main agricultural products are non-food or flex crops (sugar cane and jatropha, for example). As far as the plantations are concerned, a single product – rubber – makes up almost half of all plantations (140,000 ha). This low diversity points to a high dependency on international markets and price fluctuations.

Interestingly, most of the land granted to investors is located in accessible and relatively well-off regions (Figure 1). The investors' demand for accessibility seems to outweigh the government's aspirations to use land acquisitions for regional development, especially in marginal areas with poor infrastructure.

A substantial transition in agricultural production is under way.

Almost half of the granted lands were formerly small-scale agricultural landscapes with a mosaic of cultivated land, bush fallows and patches of forests. Crops grown in, and the forest products and other edible material gathered from, these landscapes are a crucial element of the food security, particularly of the poorer households of local communities (Foppes and Ketphanh 2004, De Schutter 2011). Also, prior to their transformation such multifunctional landscapes provided an array of ecosystem services such as, for example, preserving biodiversity and sequestering carbon.

The wide range of services delivered by multifunctional landscapes challenges the wisdom of the homogenisation trends currently being witnessed in the global South. This is relevant to the continuing debate (for example, Fischer *et al.* 2011 and Castella *et al.* 2013) on whether agricultural production should: a) make use of multifunctional landscapes (land sharing) or b) target existing cultivated or marginal lands thereby setting aside other areas, for example for biodiversity conservation (land sparing). Opinion seems to be converging on the understanding that the former alternative – land sharing – is preferable overall, although trade-offs have to be accepted in certain intensively used areas. The holistic, land-system architecture proposed by Turner II *et al.* (2013) promises to further improve our understanding of the human-environment systems with a view to devising options to mitigate and adapt to global change.

Lessons from Laos

The nations targeted for large-scale land acquisitions are often portrayed as offering abundant land reserves in combination with high yield gaps. The Laos analysis challenges this portrayal by showing that investments target high-value and easily accessible land. This push from investors for the best land had been reported before (see Cotula 2012) but lacked confirmation from detailed national studies such as the present one.

The global picture and the data for Laos both suggest that far from being located on "idle lands", much of the investment targets agricultural landscapes used by smallholders leading to land conflicts. Smallholders tend to be at a comparative disadvantage in such conflicts and are hence frequently the losers. Even if the conflicts were to be mitigated, it remains valid to challenge the prudence of large-scale, fossil-fuel-dependent monoculture replacing smallholder systems. Particularly when it threatens the food security of a large percentage of the population. No wonder, then, that there have been calls to re-evaluate the future of agriculture and its related economic, environmental and socio-cultural benefits and costs (e.g. De Schutter 2012, IAASTD 2008).

Land acquisitions by foreign corporations/nations can be portrayed as helping to foster agricultural intensification, modernisation and poverty alleviation from a macroeconomic perspective. At least for Laos, such claims receive little support at the sub-national level given the observation that investment tends to avoid the most needy areas. Indeed, past experience shows that the negative impact of the loss of access to land – often arising from a disregard of customary land rights (IIED 2012) – tends to outweigh the potential local benefits of the Foreign Direct Investment.

An effective dialogue on land investments requires reliable data on the global as well as national level. This is now being addressed through various initiatives, for example the Land Observatory initiative of ILC (International Land Coalition) and CDE (Centre for Development and Environment) of the University of Bern). At the same time, we need to better understand the land-grab phenomenon in the context of globalisation and its attendant specificities of trade, governance and power (see Margulis *et al*. 2013). The insights yielded by a combination of these two approaches could pave the way for policies and innovations in governance that help safeguard underprivileged communities from exploitation. ▮

Much of the investment targets agricultural landscapes used by smallholders.

Box 2. A look at Laos

Laos is a mountainous country in the heart of mainland Southeast Asia endowed with abundant natural resources. It ranks as one of the poorest countries in the region. The last decade has seen an unprecedented transformation of land use in rural areas fuelled by government policies in support of growth and a market-based economy. Laos has emerged as a supplier of raw agricultural commodities, plantation products and minerals as well as hydropower for the large and dominant economies of China, Thailand and Vietnam that share its borders. Almost half of the growth in Gross Domestic Product of between 7 and 8% comes from the natural resource sector (dominantly mining and hydropower). A majority of the rural population continues to depend on small-scale and often subsistence-only agriculture for their livelihood. Laos is ruled by the communist Lao People's Revolutionary Party. This implies that all land belongs to the state and that investors can get access to land through land leases or concessions (typically between 25 and 50 years).

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WHAT TO DO WHILE THE WATER RISES?

Rising sea levels will eventually threaten many coastal cities. But a dominant focus on the long-term endgame should not unduly restrict our options to deal with the more immediate consequences of climate change, says **Richard Little**.

Superstorm Sandy's aftermath in New York demonstrated unequivocally that extreme weather events are not solely the scourge of developing nations in the tropics. We know that sea level will continue to rise in a warming world and, pending action, substantial parts of coastal cities around the world will eventually be inundated. As with other aspects of climate change, discussion of sea-level rise is often framed in terms of the long-term outlook. For example, we are told that sea level by the end of the 21st century could be higher than the present level by over half a metre[1]. There is much emphasis on emissions reductions; however, not only does this face political obstacles, there are also considerable technical hurdles.

For example, recent work[2] suggests that providing the new electrical generating capacity needed by 2050 and merely maintaining the current levels of atmospheric CO_2 would require the construction of the equivalent of 10,000 new 1 GW nuclear plants in the next 40 years – a technical and financial impossibility. So, despite expectations of an increased frequency of some extreme weather events[3], emissions reductions realistically achievable in the short to medium term would probably have little or no impact on the frequency and magnitude of those events.

Planners should think hard before committing billions on floodgates for New York.

Getting the timescales right

The recognition that mitigation is not going to be sufficient has stimulated much work on climate-change adaptation in the coastal zone. But we remain far from providing the sort of detailed information and forecasts that adaptation policies need. For today's policymaker, risk manager or design engineer, it is not sufficient to know how much sea level might rise by the end of this century or in two centuries. Will the rise be constant and linear or will it be faster or slower at the beginning or end of the time period? What is the probability that a specific increase will be seen within a specific time frame? What can be done to make a community safer from the next storm event? Global averages are not very helpful either. For example, we know that sea-level rise will not be the same in all parts of the world: urban regions located on subsiding deltas will be more vulnerable as will cities in poorer nations. When the options include spending billions for flood defence or abandoning valuable land and infrastructure, such details matter.

Concentrating on what might occur far in the future introduces several complications. For example, it renders our standard economic decision tools less valuable. Economists have a way of valuing future benefits; a practice called discounting. Using this technique, something of great benefit to people in 2100 may not be economically viable – even if morally more appropriate – today. Another complication of a long-term focus is the lack of urgency. Because humans tend to organise for action based on real or imagined deadlines, we find it difficult to muster the will to address something that will occur long into the future. Building a timeline of integrated steps where the role of each generation can be easily discerned may be more effective. Finally, by taking it upon ourselves to "fix" a problem 200 years in the making ignores the ability (or desire) of succeeding generations to develop their own solutions based on what will have been learned in the intervening years as well as technological advances that we cannot foresee.

What would we do if the sea-level rise were solely due to natural factors? Based on past practices, we would most likely build defences to keep water out, construct buildings and infrastructure to withstand the effects of storms and flooding, and ultimately move to higher ground. In current disaster jargon we would become more resilient. Meaningful resilience is achievable without burdening the present unduly or abandoning future generations.

Managing risk

The UN estimates that by 2050 two-thirds of the world's population will live in urban areas[4]. Of these, more than 5 billion will be living in "less-developed regions".[5] This makes coastal cities in the developing world particularly vulnerable.

Two aerial photographs showing a portion of the New Jersey coastal town of Mantoloking, just north of where Hurricane Sandy made landfall.

Remote Sensing Division of the National Oceanic and Atmospheric Administration (NOAA)

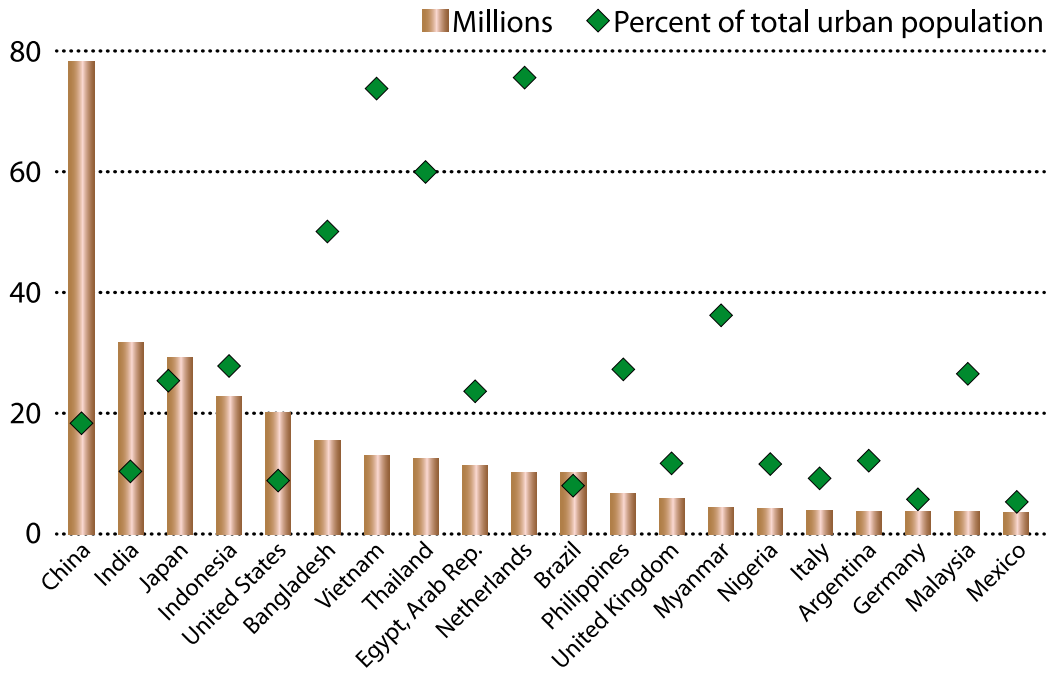

Figure 1. Urban populations at risk. The figure shows countries with the highest urban populations living in low-elevation coastal zones in the year 2000. Modified after Figure 4b from "Cities and climate change: an urgent agenda." The World Bank. December 2010, vol. 10, page 9. http://goo.gl/nTVg5.
Data source: CIESIN (Center for International Earth Science Information Network).

Basic services such as reliable electric power, clean water, and basic sanitation are often lacking, and the absence of proper planning has tended to force the poorest people to occupy the most marginal and susceptible land.

But coastal vulnerability is not solely a problem of the less-developed world (see Figure 1). In 2011, this vulnerability was vividly demonstrated at Fukushima, Japan, and just recently in New York. Achieving a single, globally applicable solution is not likely but this should not preclude the development of a general framework from which nationally or regionally appropriate solutions may be generated.

Because of the great uncertainty of predicting the magnitude of specific events at specific locations, this general framework should be based on a structured approach to risk management that can be summarised in three sequential actions: avoid the hazard if possible, withstand its effects and recover from its impacts.

New Orleans is now hostage to decisions made 100 years ago.

Avoid the hazard

The only way to avoid extreme weather events is not to be there when one occurs. In the case of coastal areas, for example, living outside the possible inundation zone associated with storm surge is perhaps the wisest choice, though certainly not an immediate option for the many people already living in flood-prone areas. However, better identification and delineation of floodways and flood-prone areas coupled with the implementation of appropriate land-use planning and regulatory tools could lead to more resilient development patterns. The location of new facilities and infrastructure should take account of future hazards and when facilities require major reconstruction, relocation to higher elevations should be mandated[6].

Withstand the hazard's effects

Despite the inevitability of rising sea level, it is probably too costly for the foreseeable future to relocate all existing vulnerable developments and infrastructure to safer ground. Levees and flood walls are obvious options, so too is elevating existing structures. Engineers are good at designing and building for known hazards, and building and design codes to improve hazard resistance have proven their effectiveness through countless major events. However, the traditional approach is to design for the worst-case scenario based on previous experience. Although it is comforting to believe that designing for a maximum probable event fully addresses the potential risk, recent history suggests otherwise. The designers of the Fukushima Daiichi nuclear plant in Japan applied what they believed to be a rational tsunami threat scenario; yet, it proved woefully inadequate. To a large extent, engineering design practice for "natural" hazards assumes that the Earth of the future will behave much as it has in the past but this is probably no longer true.

In light of this, planners should think long and hard before committing billions on structural solutions such as floodgates for New York. There are abundant examples of how the installation of physical flood defences creates a dependency from which it is difficult or impossible to deviate. For example, New Orleans and the entire Mississippi River Basin in the US are now hostage to decisions made nearly 100 years ago to install massive levees and flood walls. Not only do these structures require constant care, we have since learned that there are cheaper, more effective and more environmentally friendly solutions that now cannot be implemented. Of course, a city such as New York, London, or Shanghai must be protected but a realistic plan for flood defence must recognise that not everything can be protected equally. Also, we do not yet know, and perhaps never will, the magnitude of the event that we should design for. Under these conditions, flood

defence needs to be flexible and scalable so it can be modified as conditions change and we learn how to better address them.

Recover from the hazard

Despite our best efforts to avoid hazards they occur nevertheless, usually presenting some hitherto unanticipated aspects. How societies recover from them will depend on the degree to which they have invested (mentally, physically and fiscally) in the basic building blocks of a resilient society. The key to resilience is institutional competence. Whether a single government organisation or a collaboration of public, private and NGO elements, there must be an entity committed to ensuring that capacity exists at all levels (e.g., governments, businesses, individuals) to respond to the unexpected in a manner that ensures that the societal organisation will endure. This point is critical. Without such commitment, planning and preparation efforts will prove to be a hollow exercise once an event occurs.

In this regard, Jared Diamond may prove prophetic. In his study of extinct societies he identified four reasons why societies have made disastrous decisions that ultimately caused them to disappear[7]: a) failure to anticipate a problem; b) failure to recognise a problem that's already arrived; c) failure to try to implement solutions; and d) denial of the problem. We have seen all of these stages play out at some point in the climate-change discussion.

Being informed about the risks of climate change can help, though, as indicated by a study published in the journal *Nature Climate Change*[8]. This study modelled the response of coastal areas to climate risk by using a coupled physical and economic model. The results suggest that relative to those with little faith in climate model predictions, informed property owners "invest heavily in defensive expenditures in the near term and then abandon coastal real estate at some critical risk threshold that presages a period of significant price volatility".

Building resilience

Resilience in the face of climate change in general and sea-level rise in particular is a global challenge. Wealthy nations have the resources to address issues of monumental scope and scale so they will have an advantage. However, although many nations in the developing world are particularly vulnerable, there is a path that is not purely dependent on the amount of money available. First and foremost, these nations should strive to develop indigenous capability to organise for improved resilience. Local officials would bring to this task what others cannot: a dedication to bettering their own nation[9]. Indigenous capacity alone will not result in resilient communities but without it, improved resilience will not become reality.

Finally, although climate change will add to the global risks faced by vulnerable populations, it must be remembered that the world has a long history of extreme weather and other natural hazards. Focusing solely on climate change in hazard preparedness and resilience will paint an incomplete picture of the risks and complicate discussions of how best to address them. Although it is obvious that climate change will affect the global risk profile for decades to come, much of what needs to be done is actually independent of it. For example, providing improved emergency warning systems and moving people out of high-risk locations was a priority long before climate change became an issue. How well these changes and their impacts are anticipated and addressed will have a profound effect on the lives and economic wellbeing of hundreds of millions of people now and in the future.

The world has a long history of extreme weather and other natural hazards.

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5. The less developed regions comprise all regions of Africa, Asia (excluding Japan) and Latin America and the Caribbean as well as Melanesia, Micronesia and Polynesia.

6. Had the emergency electrical generators at Fukushima Daiichi been located above the tsunami inundation zone, much of the resultant radiological disaster would likely not have occurred.

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9. For example, Bangladesh has implemented a comprehensive, end-to-end mitigation, warning, evacuation, and sheltering system. Comprising 123 sea- and inland-facing polders, extensive replanting of mangrove forests, early detection, warning, and evacuation supported by more than 2400 purpose-built cyclone shelters, the system is credited with saving thousands of lives.

URBAN air pollution: a new look at an old problem

Large urban agglomerations inevitably lead to air pollution. But despite the significant impacts on human health and climate, we lack systematic measurements of air pollution in many cities. **Megan L Melamed**, **Tong Zhu** and **Liisa Jalkanen** discuss a new global assessment that illuminates the knowns and unknowns.

London has been intimately familiar with air pollution since medieval times, but the winter of 1952 nevertheless came as a rude shock: the city was blanketed by smog that persisted for four days. Known as "The Great Smog", this event is estimated to have caused 4000 premature deaths. Los Angeles too had encountered severe smog in the 1940s. These events served as wake-up calls, prompting the US and UK governments to enact legislation and set air-quality standards in the 1950s. As a result, today's residents of London and Los Angeles breathe much easier.

Those residing in other cities aren't so lucky. Two recent media articles highlighted the air pollution in Beijing and Salt Lake City, two cities on opposite sides of the world. In both cities, the combination of emissions and weather conditions leads to smog. And despite the advances made by London and Los Angeles, the concentrations of particulate matter in these cities remain higher than the limits set by the World Health Organization (WHO; Figure 1).

Air pollution is clearly a pernicious problem.

Air pollution is clearly a pernicious problem and its health impacts are set to worsen as several regions of the world urbanise rapidly. A recent report by the Organisation for Economic Co-operation and Development (OECD) says that by the year 2050, outdoor air pollution is projected to be the world's top environmental cause of mortality, ahead of dirty water and lack of sanitation (OECD 2012). But human health is just one dimension of air pollution. Unclean air also affects crop growth and reduces the productivity of agriculture (for example, Shindell *et al.* 2012). It affects climate in a complex manner. Understanding the types and spatio-temporal patterns of urban air pollution is crucial to exploring its implications for human and ecosystem health, food security and climate.

In September 2012, the World Meteorological Organization and IGBP's International Global Atmospheric Chemistry (IGAC) project published the first international assessment of available information on air pollution in major urban agglomerations. The report entitled *The Impact of Megacities on Air Pollution and Climate* examined data from Africa, Asia, South America, North America and Europe. It concluded: (1) air pollution continues to be a serious problem across the world; (2) the amount of scientific knowledge varies greatly between megacities; (3) there is a clear opportunity to translate knowledge from well researched urban areas to less researched urban areas to mitigate air pollution; and (4) large urban agglomerations may be the best places to realise the co-benefits of simultaneously controlling air pollution and mitigating climate change.

Assessing and improving air quality

Air pollution typically refers to a set of common substances – also

Air pollution is a challenge in cities such as Jakarta, pictured here.

known as criteria pollutants – that have demonstrable impacts on human health and ecosystems. The main culprits are lead (Pb), carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3) and particulate matter (PM). Particulate matter in the form of soot and other small particles floating in the air is usually classed as $PM_{2.5}$ (particles with diameters smaller than 2.5 micrometres) or PM_{10} (particles with diameters less than 10 micrometres). Both affect human health as well as climate. We can see from Figure 1 that across 26 cities, despite large differences in PM_{10} concentrations, even the most developed cities approach or exceed WHO air-quality guidelines.

WHO estimates that air pollution causes more than 2 million premature deaths each year (WHO 2006). In 1987, WHO published *Air Quality Guidelines for Europe*. In 2005, following important new research from low- and middle-income countries, it released new *Air Quality Guidelines* for four common pollutants (PM, O_3, NO_2, and SO_2) that are intended to inform policymakers on appropriate targets related to air-quality management (Table 1; WHO 2006).

Table 1: WHO air quality guidelines, 2006.

Pollutant	Concentration	Averaging Period
Particulate matter ($PM_{2.5}$)	10 µg/m³ 25 µg/m³	1 year 24 hour
Particulate matter (PM_{10})	20 µg/m³ 50 µg/m³	1 year 24 hour
Ozone	100 µg/m³	8 hour
Nitrogen dioxide	40 µg/m³ 200 µg/m³	1 year 1 hour
Sulphur dioxide	20 µg/m³ 500 µg/m³	24 hour 10 minute

Could newer cities learn from the experience of older cities?

The implementation of air-pollution control strategies typically occurs at the level of cities rather than at a national or international level. Each city is different. The local meteorology varies and pollutants can sweep in from long distances – even trans-continental – affecting ambient air quality. In addition, the geographic, economic, political and social contexts vary greatly across the world. Thus, air-quality control programmes will likely vary in their approach to air pollution. Policymakers and politicians must balance health risks, technological feasibility, economic considerations and various other political and social factors.

Major international events have often helped draw attention to air-quality issues and attract international research efforts. For example, in the run-up to the 2008 Beijing Olympics an international collaborative research project, Campaigns of Air Quality Research in Beijing and Surrounding Regions (CAREBEIJING), was implemented. The project was designed to study the regional air pollution processes that affect air quality in Beijing and to formulate air-pollution control strategies for the Olympics. When considered on an average annual basis, the air quality in Beijing has certainly improved although the recent smog suggests that there is some distance to travel.

Ultimately, however, the old adage "You can't manage what you can't measure" applies here. Successful implementation and enforcement of air-quality measures is dependent on access to scientific information. The megacities assessment clearly shows the disparity in scientific knowledge across large cities. Cities that have had access to high-quality information – Los Angeles, for example – have benefited. Could newer cities learn from the experience of older cities to avoid teething troubles?

Experience shows that this can indeed be the case. A prime example is shown in Figure 2, which shows how ozone and PM levels changed through time in three similarly sized megacities:

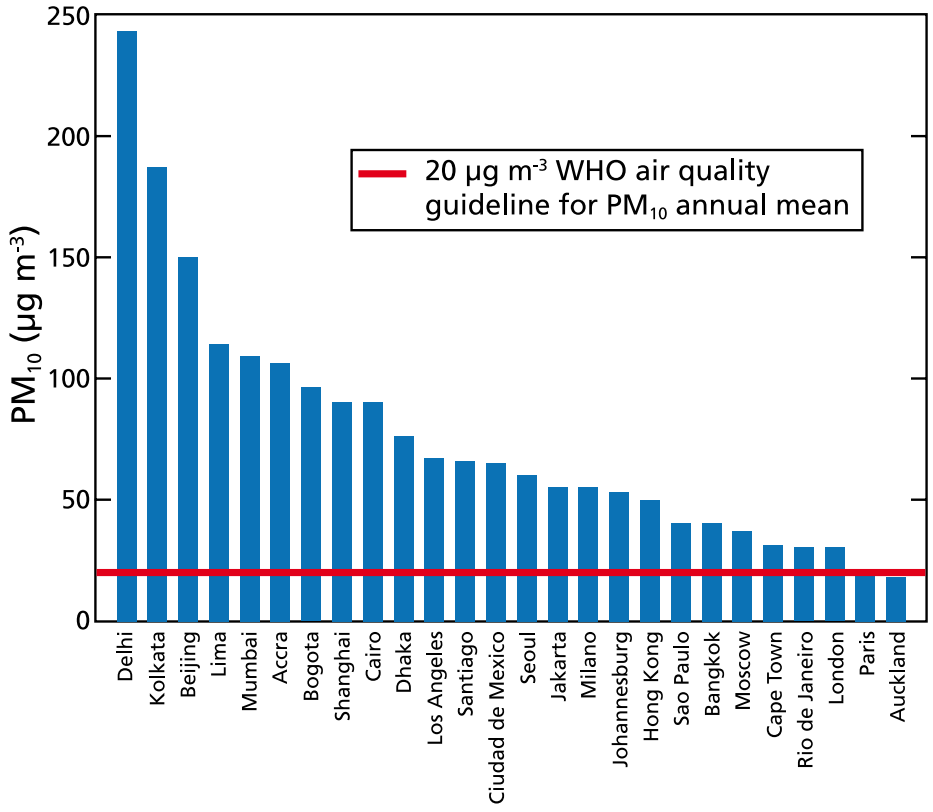

Figure 1. Comparison of annual mean concentration of PM_{10} across urban areas (Zhu *et al.* 2012).

Los Angeles, Mexico City and Beijing. During the time period depicted in the figure, each city had a population within ± 40% of the average of the three cities. In Los Angeles, ozone concentrations peaked in the early 1970s and have been decreasing over the past four decades. We can see that the ozone levels in Mexico City never reached the peaks of Los Angeles and levels fell faster. Today, the ozone and PM concentrations in Los Angeles and Mexico City are nearly the same. Mexico City avoided severe air pollution by translating the lessons of Los Angeles to implement emission controls.

Beijing, however, seems to be on a different track. PM concentrations remain higher than the two other cities but are decreasing. In contrast, ozone concentrations, which have been low, are rising. As mentioned earlier, Beijing has taken numerous measures during the past few years to control air pollution. Assessing how these measures are working will not only help Beijing to fine-tune its policies but will also hold lessons for more recently urbanising centres.

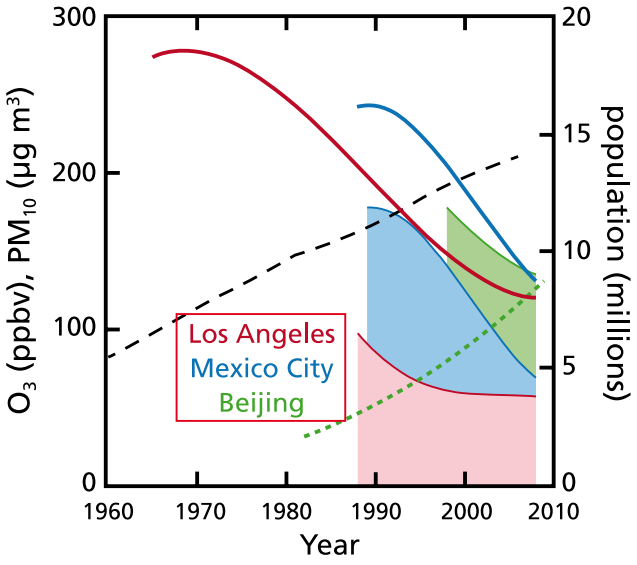

Figure 2. Comparison of the evolution of ambient ozone (solid and dotted thick lines) and PM_{10} (thin lines shaded to zero) concentrations in three megacities of similar populations. The black dashed line shows the trend of the average population of the three cities. (Zhu *et al.* 2012).

An integrated approach

Although the impact of big cities on local air quality has long been recognised, the impacts on regional and global climate are beginning to receive increased attention. We know now that air pollutants can drive climate change in complex ways (see Arneth *et al.* 2009, for example). Many pollutants (such as sulphur dioxide) form tiny droplets that deflect incoming solar radiation and tend to cool the climate. Pollution control policies that reduce the atmospheric concentrations of such substances can in fact lead to warming. Other pollutants – black carbon (soot) in particular – can absorb incoming solar radiation and lead to warming. Because black carbon is also a significant health hazard, policies aimed at controlling the emissions of this substance could lead to a win-win scenario (see page 9 of this issue).

With this emerging understanding, there is little justification for keeping air pollution and climate change in separate boxes. These are issues with overlapping temporal and spatial scales and should be addressed in an integrated manner. It has been argued that megacities and other large urban agglomerations are the best places to realise the co-benefits of simultaneously controlling air pollution and tackling climate change.

The *WMO/IGAC Impacts of Megacities on Air Pollution and Climate* assessment sought to evaluate the current state of knowledge and identify gaps. It reveals that the quality and quantity of available information is highly variable, with air pollution in some cities being much better characterised than that in others. The gaps underscore the need for continued international efforts to measure urban air quality and use this information to improve air quality while simultaneously mitigating climate change. ▮

We know now that air pollutants can drive climate change in complex ways.

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A COLLISION OF WORLDS

Several communities that study the Earth's land do not yet speak the same language. A new paradigm in Earth-system modelling will emerge when these communities overcome language barriers, says **Eleanor Blyth**.

Imagine a world where the only requirement is that you can sing in tune. Then picture a world where the sole obligation is that you can write poetry. And finally, think of a world where your performance on stage trumps all else. Now imagine bringing these worlds together. A hierarchy in the World of Song would be based entirely on perfect pitch, eloquence triumphs in the World of Words and showmanship determines the winner in the World of Performance. Let's give them a problem to solve together: how to nurture the next generation of music stars. They may struggle to find a harmonious solution, either together or separately.

So we come to the third open science conference of iLEAPS (Integrated Land Ecosystems-Atmosphere Processes Study) held in Garmisch-Partenkirchen, Germany in 2011. Joe Berry from the Carnegie Institution for Science, Department of Global Ecology, Stanford, summarised the extraordinary place we find ourselves as we try to solve today's global environmental issues. He pointed to an essay published in *Physics Today* by John Harte who makes the point that Earth-system science falls between two traditional approaches to science that he refers to as "Newtonian" and "Darwinian".

"Newtonians" – the various types of modellers, for example – seek simplicity in universal laws exemplified by Einstein's theory of theories, "A scientific theory should be as simple as possible, but no simpler." In contrast "Darwinians" (ecologists, for example) revel in complex interdependencies. They make progress by observing complexity and develop overarching concepts like evolution.

I have been steeped in this world for 23 years.

Earth-system science is now witnessing the emergence of a new modelling paradigm that explicitly accounts for two types of effects on the climate system: a) human (for example, land-use change resulting from agriculture), and b) natural (for example, biodiversity and adaptations of natural ecosystems). The success of such models will depend on the collaboration among the different communities that study land-atmosphere interactions, and ultimately on the development of a common language (see Box for the many meanings of "reduction" in biology, chemistry, mathematics and plain English).

My world and theirs

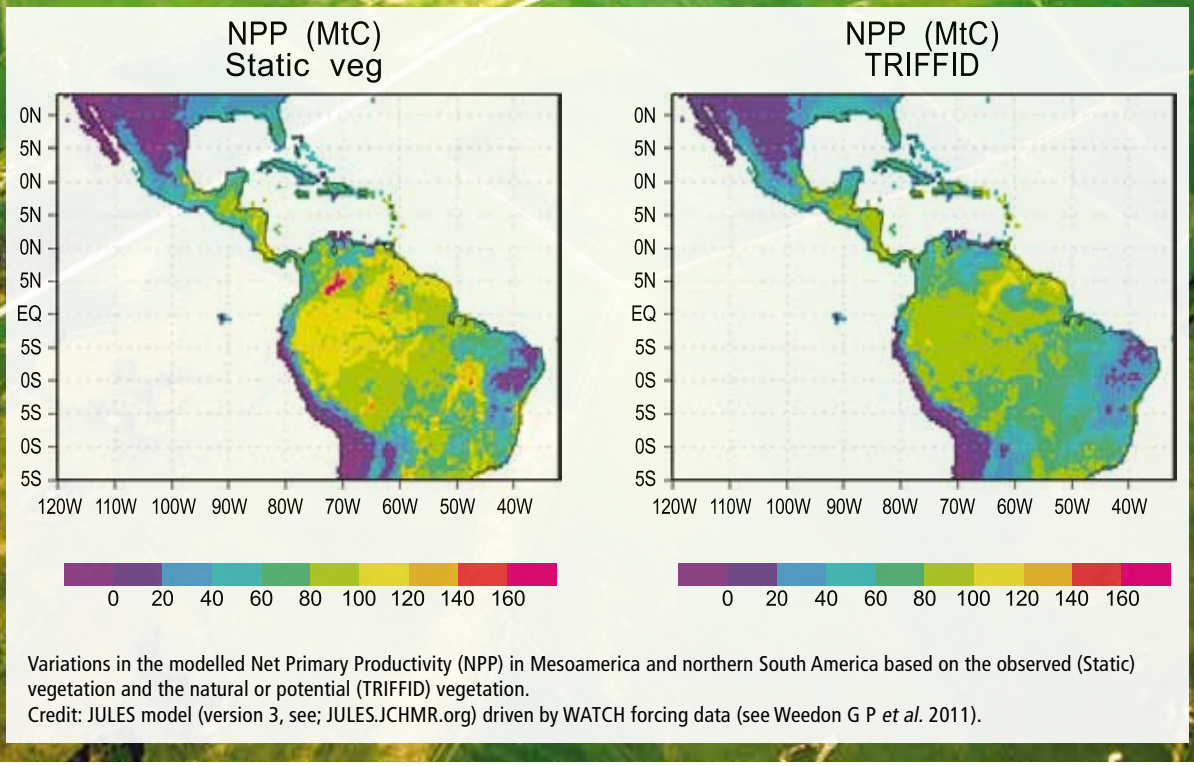
I will have to declare my discipline: I am a land-surface modeller working on JULES (Joint UK Land Environment Simulator). JULES, which includes representations of the many land-atmosphere interactions, sits within the UK Hadley Centre climate model. In my "world" what matters is the correct calculation of all physical exchanges with the atmosphere: radiation, heat, water, momentum and carbon fluxes (carbon dioxide and methane). The skill is to understand the processes that determine those exchanges. For example, the effect of snow and vegetation on heat radiation and turbulent exchanges; the soil hydraulic and thermal processes that control the availability of water and heat.

In my community, we bury ourselves in equations and computer code, and in datasets that detail the vertical exchanges of matter and energy. We increasingly turn to large-scale satellite datasets that tell us how the land surface is responding to weather changes. When we use words like "region" we mean continent; when we talk about "fluxes" we mean vertical exchange of carbon dioxide, water or heat. I have been steeped in this world for 23 years.

The models are reasonably precise in their portrayal of the interface between the land and the atmosphere. However, they're somewhat blinkered. So far, they have not included detailed descriptions of the 37% of the Earth's surface outside of the ice sheets that is covered by the imprint of humanity: agriculture (11% crops and 26% pasture). This area is represented as natural grassland, but the models exclude land management (Figure 1a).

Meanwhile, a group of land-use

Complex landscapes pose modelling challenges.



Variations in the modelled Net Primary Productivity (NPP) in Mesoamerica and northern South America based on the observed (Static) vegetation and the natural or potential (TRIFFID) vegetation.
Credit: JULES model (version 3, see; JULES.JCHMR.org) driven by WATCH forcing data (see Weedon G P *et al.* 2011).

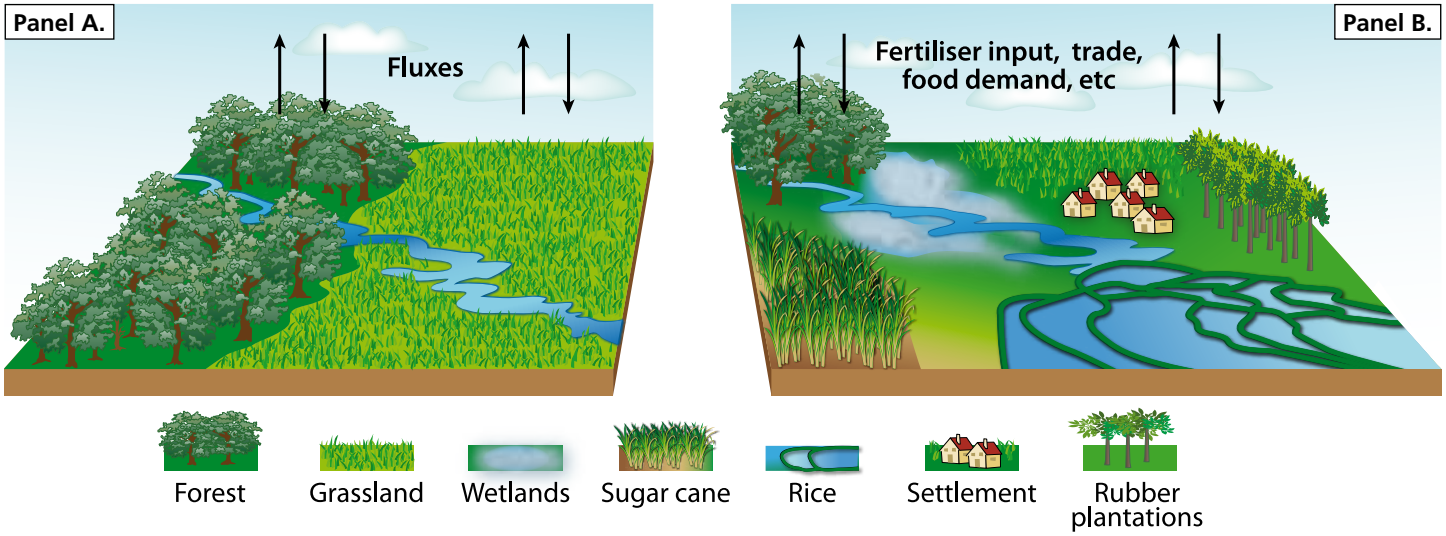


Figure 1. Simple or complex? Panel A shows a relatively simple, natural landscape as conceptualised by land-surface modellers. Panel B shows a more complex, human-dominated landscape as conceptualised by the land-use modellers. Exploring the interaction of the human food footprint with climate change will rely on combining these perspectives.

modellers study agricultural land in great detail. Their models include harvesting, sowing, tillage, fertiliser application, crop types and, most importantly, yield (Figure 1b). These models are run at the global scale and incorporate things like population demands for food and fuel and world trade of these commodities. With a 30% increase in population within 30 years looking likely, land-use change associated with food and fuel production will be a substantial player in global change. Clearly, Earth-system models must include current and future land-use.

And then there is the ecology and biodiversity community, which reminds us that the "forests" and "grasslands" of land-surface models are in fact complex admixtures of plants. This complexity may influence how vegetation affects and is affected by climate (see model outputs on page 25). It may also influence the services that ecosystems provide, for example food, carbon sequestration, etc. As recent modelling of the response of forests to climate change shows, the differences in how plant physiological processes are represented contributed most to the uncertainty in the model projections (Huntingford *et al.* 2013). No wonder, then, that this community spends considerable effort in characterising plant traits such as morphology, physiology and biochemistry in great detail.

Learning to communicate

Facilitating the emergence of a new paradigm in modelling requires that we get these various groups talking, if not singing. We've started negotiating the languages, the scale of the modelling and the level of detail to insert into models. But many challenges remain.

For instance, land-surface models often include only five types of vegetation for the entire natural world. This includes only one "type" of broad-leaf tree to characterise the Amazon rainforest as well as temperate forests of trees such as oak, beech and aspen. In contrast, crop models include ten times as many crop types. This mismatch is cultural and scientific. The discrepancy between the two approaches lies in what the model is trying to achieve: predictions about which crop to grow or understanding how land-cover affects atmospheric circulations. The former requires more detail than the latter, but ultimately we want to bring the two together to explore the interaction of the human food footprint with the changes in the climate.

We're making progress. Recent projects (for example, LUCID; Pitman *et al.* 2009) brought together a suite of modellers to bridge the gap and identify issues when including agriculture into land-surface models. Meanwhile, it is likely that the new-generation land-surface models will include more ecologically realistic plant types, for example by using the Plant Trait Database that has been collated under the "TRY" project co-sponsored by IGBP (http://www.try-db.org/TryWeb/About.php). Then we will be able to better understand the footprint of humans on the climate system.

Understanding the role of

The many meanings of "reduction"

Plain English: The amount by which something is lessened or diminished.

Biology: The first meiotic division.

Chemistry: A decrease in positive valence or an increase in negative valence by the gaining of electrons or reaction in which hydrogen is combined with a compound or a reaction in which oxygen is removed from a compound.

Mathematics: The cancelling of common factors in the numerator and denominator of a fraction or the converting of a fraction to its decimal equivalent or the converting of an expression or equation to its simplest form.

biodiversity on the climate system is the subject of a new European-South-American project, The Role of Biodiversity in Climate Change Mitigation, or ROBIN (http://robinproject.info). As part of the project, I am investigating how to incorporate more biodiversity into JULES so that the world is not modelled as a series of monocultures. Once that has been done, we will use the model to study whether including a variety of species within a region makes a difference to any of its ecosystem services.

For instance, ecosystems with high biodiversity may sequester more carbon. A number of mechanisms have been mooted to explain this process. Cardinale *et al.* (2011) reviewed around 15 years of experiments on temperate grasslands and concluded that high-diversity ecosystems have higher productivity than the average across individual monocultures. But – and here is the vital point – the productivity of the polyculture rarely exceeds the productivity of the most productive species in the mixture. If these results were to scale up to real ecosystems, it would be fair to conclude that monoculture involving the most productive species achieves the greatest productivity. In the Arctic, too, scientists on the international ABACUS project (Arctic Biosphere-Atmosphere Coupling across multiple Scales) showed that the carbon sequestration was reduced at the location where plants physically overlap (Fletcher *et al.* 2009).

Nevertheless, some other studies do point to a stabilising effect of biodiversity and find an increase in community biomass. The question therefore remains: do forests with greater biodiversity sequester more carbon than monoculture forests? What is the mechanism? And could it be that highly diverse forests are more resilient to climate change (for example, to droughts)?

These seem like reasonable scientific questions, which will benefit from greater collaboration between the concerned communities. Ecologists and biodiversity scientists often use language and concepts that are qualitative (e.g. habitat quality). Land modellers of various types tend to favour quantitative language and concepts. Negotiating a common language and vocabulary to make the emerging paradigm a reality is the need of the hour.

The age of the music star

We at the ROBIN project held lofty ambitions about creating music stars. Words and definitions came first. The project settled on three types of biodiversity: species diversity, functional diversity and structural diversity. The first is the traditional definition: how many species are there (and this can include animals as well as plants)? The second is a modeller's perspective: is there variation in how the plants affect climate? And a final one from the Earth Observation community: what kind of diversity can we see from space? The idea is to bring these three definitions into one analysis framework, working at different scales and with different communities. The project also aims to bring the land-use modellers into the arena – which brings us back to the issues discussed above.

In November 2012, ROBIN held its second annual general meeting in Santa Cruz, Bolivia. Half the attendants were from European countries and the other half were from Latin America (Mexico, Guyana, Bolivia and Brazil). They ranged from modellers and Earth observers to field workers and social scientists. The language was mainly English but half the participants were more comfortable in Spanish. The issues ranged from carbon budgets to tree species in the tropical forests and the farming practices of the different regions. Having discussed at length how we include key elements of biodiversity in the JULES model, such as incorporating more than one type of broadleaf tree (especially those that are drought resistant), we then went on a trip into the jungle. We walked through the trees, smelling leaves, looking at special plants whose seeds land in the arms of other trees and who then send tendrils down to the soil to start a rooting system.

I staggered out of that forest singing the praises of these Darwinians: how could we possibly describe this incredible variety with even a few tens of thousands of lines of computer code? Despite the challenges, I believe we will find harmony. Some processes can be described more simply than we do at present. The future will teach us that we are not all that different after all. I intend to enjoy every step of the way along this very diverse path. ▮

Despite the challenges, I believe we will find harmony.

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