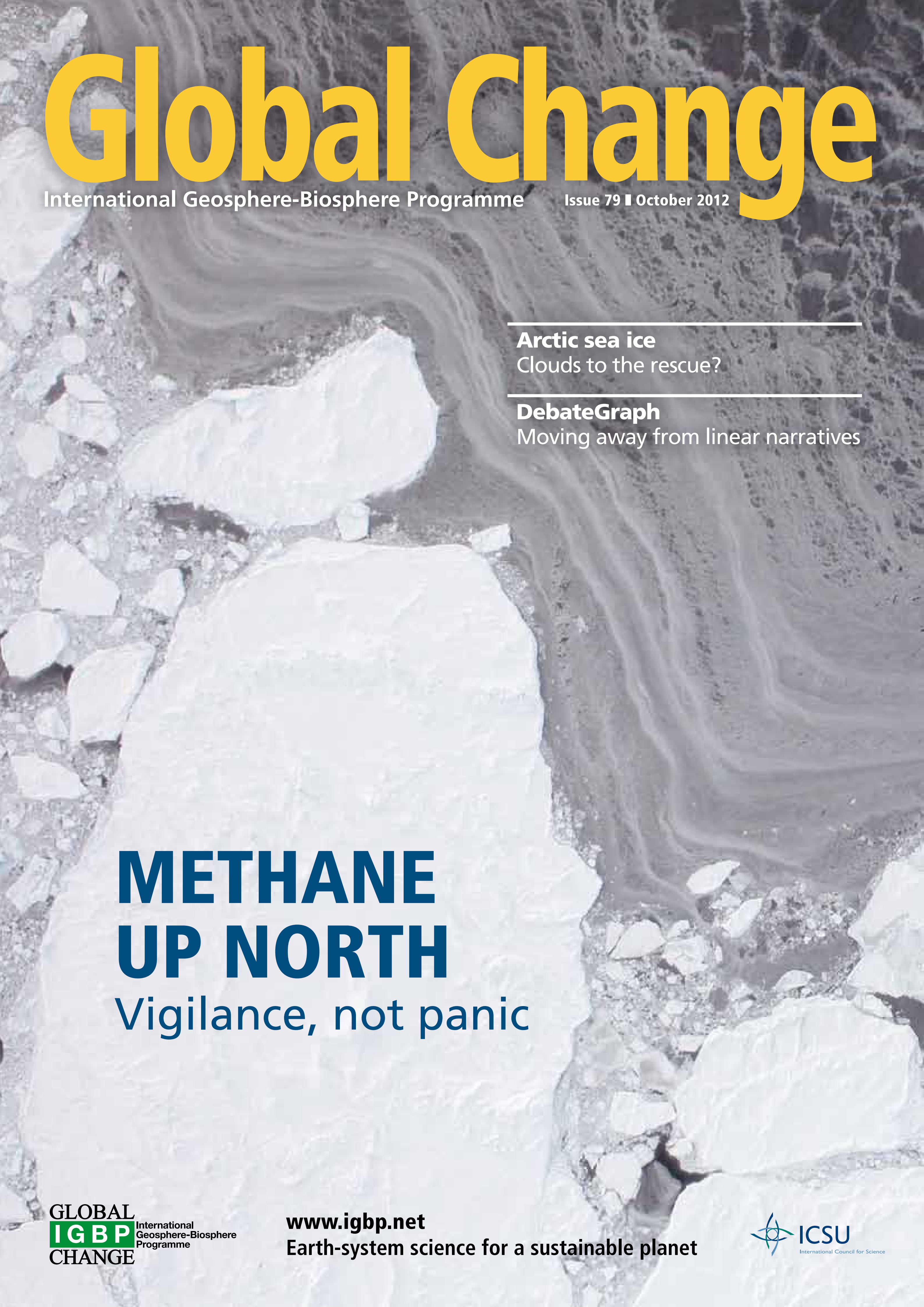


# Global Change


International Geosphere-Biosphere Programme

Issue 79 ▮ October 2012


**Arctic sea ice**
Clouds to the rescue?

**DebateGraph**
Moving away from linear narratives

## METHANE UP NORTH

Vigilance, not panic


GLOBAL IGBP CHANGE International Geosphere-Biosphere Programme

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

ICSU International Council for Science

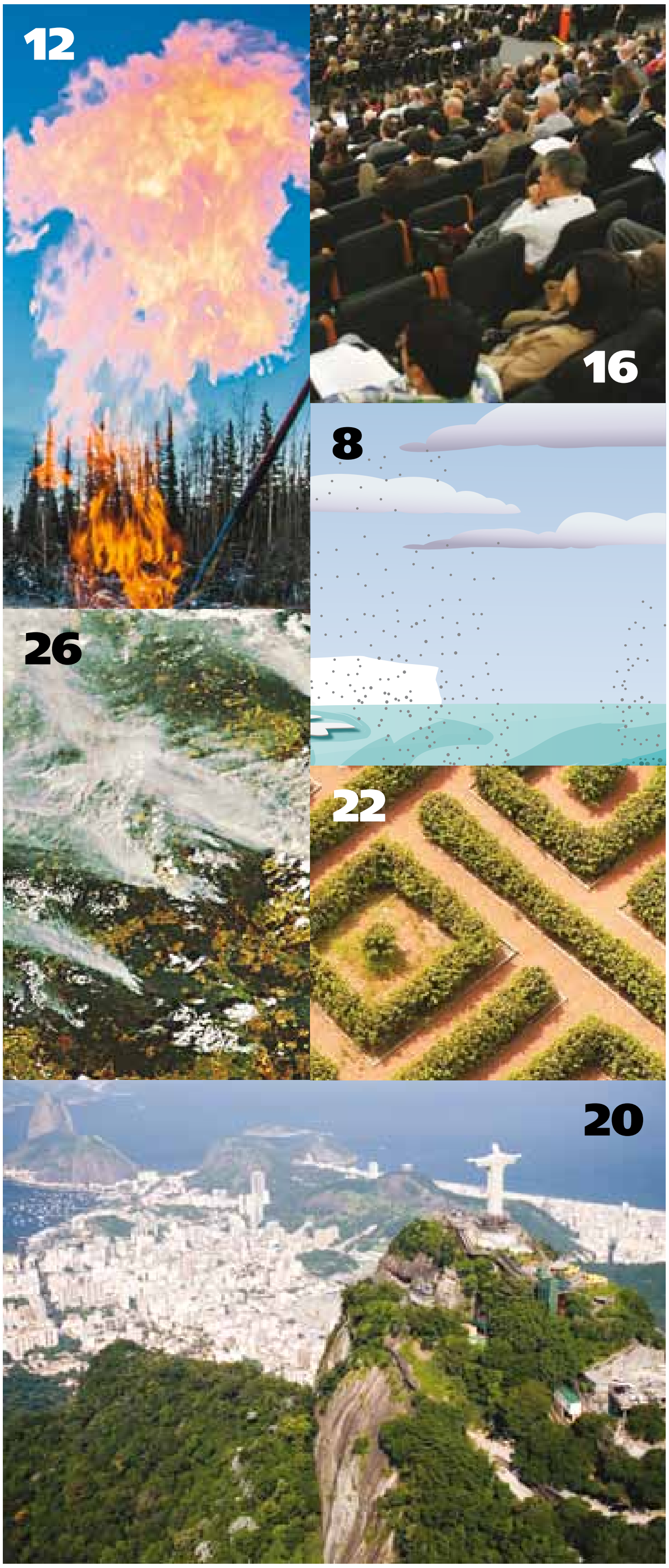
# Contents



**Cover image**

Aerial photograph of Arctic sea ice. The image shows thick, snow-covered ice floes (white) and thinner ice (darker and semi-transparent). The white stripes are layers of thin ice along the edges of the floes. Image courtesy NASA (the Digital Mapping System team and Operation IceBridge Arctic 2011).







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Sybil Seitzinger, Executive Director, IGBP

The record low in Arctic sea-ice extent this summer was probably this year's biggest global-change story. According to the National Snow and Ice Data Center, the area covered by sea ice last month represents a 45 percent reduction as compared with September conditions in the 1980s and 1990s.

Meanwhile, the past couple of years have witnessed a renewed focus on methane emissions from the region, and particularly the stability of methane hydrates. Clearly, Earth's northernmost regions are changing rapidly. It is fitting, then, that these regions form the focus of several articles in this issue of *Global Change*.

Matrai and Leck highlight the role of marine micro-organisms in supplying the particles that go on to form cloud condensation nuclei in the Arctic. They explore the intriguing possibility of a negative feedback that could counteract the melting of sea ice. This possibility opens up exciting opportunities for research at the intersection of physical and biological systems. But it also highlights the complexity of processes that need to be taken into account to understand Arctic change.

Bondre joins the continuing discussion about the possible dangers posed by Arctic methane. His assessment is similar to that of many others – that although an ever-warming Arctic will release more methane than it currently does, the evidence at hand does not indicate imminent catastrophe. But there are poorly quantified interconnections and interdependencies among a number of processes, and hence the possibility of abrupt change: this is why interdisciplinary approaches are so important.

These articles add to the picture of an environment in flux. Anthropogenic global warming is undoubtedly a dominant driver of change in the Arctic. But the complexity of interacting processes and the poorly understood role of some components – clouds, for example – makes projecting future change challenging. There can be little disagreement about the need for continuous monitoring using all tools available at our disposal. Downy discusses how the European Space Agency is collaborating with researchers from IGBP and other organisations to do just that.

All IGBP projects contribute in one way or another to enhancing our understanding of the fragile northern regions. In the past couple of years, the projects have mapped Arctic coastal erosion, explored the carbon budget of the Nordic Seas, tracked ocean acidification, measured methane emissions and assessed the impact of black carbon deposition. Activities have included assessments of the effects of current and anticipated change on human societies.

Next year, IGBP will expand its second synthesis to distil the overarching scientific insights from the programme's research during the past decade. We hope that some of these insights will provide a nuanced picture of the changing climate and environment in the Arctic.

> “They explore the intriguing possibility of a negative feedback that could counteract the melting of sea ice.

www.anthropocene.info

## Anthropocene film kick-starts Rio+20

A THREE-MINUTE film, *Welcome to the Anthropocene,* co-produced and directed by IGBP's Director of Communications Owen Gaffney, opened the Rio+20 summit in front of 188 heads of state and ministers. The film was introduced by UN Secretary-General Ban Ki-moon who mentioned IGBP and the Planet Under Pressure conference. The summit attracted 50,000 people.

The short film, which was created as part of the first online educational website dedicated to the Anthropocene (www.anthropocene.info), quickly became an online sensation.

Since its launch at the Planet Under Pressure conference it has been viewed about 800,000 times and articles on it have appeared on the New York Times, BBC, Time, the Atlantic, Gizmodo and other influential sites.

"The feedback for this project has been tremendous. We achieved all our primary goals," said Owen Gaffney.

## Future Earth launched

A NEW ten-year international initiative on global environmental research for sustainability was launched at the mammoth UN Rio+20 summit in June.

The initiative, Future Earth: Research for global sustainability, aims to provide a cutting-edge platform to coordinate scientific research internationally.

Future Earth, which will include IGBP and several other global-environmental-change programmes, will be designed in partnership with governments, business and, more broadly, society. The initiative is scientifically sponsored by an alliance of partners, including the International Council for Science (ICSU), the International Social Science Council (ISSC), the Belmont Forum of funding agencies, the United Nations University, the UN Environment Programme and UNESCO, with the active engagement of the World Meteorological Organization (WMO).

"The future of IGBP is very much with Future Earth. We recognise that the international research agenda must develop a strategic focus on global sustainability," said IGBP Executive Director Professor Sybil Seitzinger.

But endorsement comes with caveats. Future Earth was the main item on the agenda of IGBP's recent scientific committee meeting, held in Bergen, Norway, in May.

The committee supported the idea of Future Earth but called into question the process developed by the alliance of partners. In a strongly-worded letter sent to ICSU President, Professor Yuan Tseh Lee, IGBP criticised the process saying, "The IGBP Scientific Committee supports the aspirations of the Future Earth initiative, but has strong concerns about the minimal engagement to date with IGBP, and the lack of detailed science and implementation plans."

Despite ongoing difficulties, three global-environmental-change programmes – IGBP, DIVERSITAS and the International Human Dimensions Programme on Global Environmental Change – have signalled their willingness to merge into a new single organisation. The World Climate Research Programme (WCRP) will be an independent partner, supporting Future Earth strategically and intellectually.

To co-design the Future Earth research agenda, further consultations will be held in 2012 and 2013 including an online consultation. Workshops will be held in Africa, Asia and Latin America between October and December 2012.

More information: www.icsu.org/future-earth

## A different take on wealth

CONVENTIONAL means of measuring a nation's wealth do not sufficiently account for the state of natural resources or ecosystems. Moreover, they do not consider the long-term sustainability of national policies. The Inclusive Wealth Report, launched at Rio+20, seeks to rectify the situation by providing a new tool: the Inclusive Wealth Index. Results show changes in inclusive wealth from 1990 to 2008 and feature a long-term comparison to Gross Domestic Product (GDP) for an initial group of 20 countries. The report was produced by the International Human Dimensions Programme on Global Environmental Change (IHDP) and its partners.

More information: www.ihdp.unu.edu/article/read/iwr

## Erratum

GLOBAL CHANGE, Issue 78, page 11.

The graph did not account for negative values of the climate-change index. However, the values were reported correctly. The graph has now been corrected in the online PDF version.

# EVENTS

## 2012

### October

**13-20.** DISCCRS VII: Interdisciplinary Climate Change Research Symposium. Colorado Springs, USA.

**24-26.** IIASA 40th Anniversary Conference. Vienna and Laxenburg, Austria.

### November

**28-30.** IGBP Officers' Meeting. Canberra, Australia. Preceded by the 2nd Biennial Australian Earth System Outlook Conference (26-27 November).

### December

**3-7.** American Geophysical Union Fall Meeting. San Francisco, USA.

## 2013

### January

**15-17.** Third International Symposium on Arctic Research (ISAR-3). Tokyo, Japan.

**23-25.** Climate and Beyond: Knowledge Production About Planet Earth and the Global Environment as Indicators of Social Change. Bern, Switzerland.

**28-31.** IMBER IMBIZO III. Goa, India.

### February

**13-16.** PAGES 4th Open Science Meeting. The Past: A Compass for Future Earth. Goa, India.

### March

**18-20.** First European Climate Change Adaptation Conference. Hamburg, Germany.

### April

**4-5.** Holocene Climate Change. London, United Kingdom.

**17-19.** 28th IGBP Scientific Committee Meeting. Bern, Switzerland.

Indiana University/Ric Cradick

# ELINOR OSTROM (1933 – 2012)

ELINOR OSTROM, or Lin as she was known to friends and colleagues, contradicted the received wisdom that resources such as forests, fresh water, arable land or fisheries are best managed through government intervention or privatisation.

In 2009, following a lifetime's work on common resources, Lin was awarded the Nobel Prize in Economics, the first woman to achieve this distinction. Many economists expressed surprise at the Nobel Committee's decision. Not because Lin was a woman, but because she was a political scientist rather than an economist.

Lin loved people. She loved going out in the field and observing first hand how societies looked after their resources. Time and time again her work showed that common resources were often in better shape if managed by people working cooperatively and collaboratively, rather than forced to comply through top down carrot-and-stick waving.

From Spanish irrigation schemes to Nepalese forests, left to their own devices people draw up their own arrangements that are often cheaper to operate, more equitable and easier to patrol than heavy-handed bureaucratic solutions. Moreover, the resources are frequently managed more sustainably.

In her Nobel Lecture, Beyond Markets and States: Polycentric governance of complex economic systems, she noted: "…isolated, anonymous individuals overharvest from common-pool resources. Simply allowing communication, or 'cheap talk', "enables participants to reduce overharvesting and increase joint payoffs, contrary to game-theoretical predictions. Large studies of irrigation systems in Nepal and forests around the world challenge the presumption that governments always do a better job than users in organizing and protecting important resources."

In the last two decades researchers have demonstrated that the mother of all common resources – Earth's life-support system – is under threat. Early attempts at multilateral binding international agreements have come to naught.

In her later years, Lin's attention focused on this vexing challenge. In an article that appeared days before the UN's Rio+20 summit she argued: "It would be a mistake to rely on singular global policies to solve the problem of managing our common resources."

Instead, she discussed the importance of encouraging and promoting multiple overlapping systems at different scales. These governance solutions should be designed with flexibility in mind so they can evolve and adapt rapidly to changing conditions, but also to new innovations, she argued. They must incorporate redundancy to create resilience. They must learn from one another, allowing the best ideas to spread while ensuring poorer ideas have a short life.

In an interview published in this magazine, Lin emphasised that "the polycentric approach advocates complex, multi-level systems to tackle what is a complex, multi-level problem."This became a guiding theme for the recent Planet Under Pressure conference. Lin was appointed chief scientific advisor to the conference. In this role she provided intellectual guidance to the scientific committee and helped develop the first State of the Planet Declaration, published on the final day of the conference.

Lin's health deteriorated rapidly in early 2012. Chemotherapy for pancreatic cancer sapped her strength, but she refused to give up her work.

On 12 June Lin died at the age of 78. The timing was just days before the opening of Rio+20. The summit – the largest in UN history – was charged with finding solutions to managing globally common resources. Undoubtedly Lin's work has influenced the outcome, though we will have to wait a decade or more for a clear picture to emerge.

Lin is dearly missed by the global-environmental-change community. She has inspired us all.

# JOÃO MORAIS LEAVES IGBP


The Royal Swedish Academy of Sciences/Eric Huss

A DEFINING characteristic of humans is our ability to transform our surroundings to suit our selves. As the population has swollen to seven billion, we have transformed our planet. Understanding this transformation and its implications is critical to increasing our knowledge of the Earth system. For 16 years, João Morais (IGBP's Deputy Director for Social Sciences) advised and guided IGBP and its projects towards a deeper appreciation of the social, cultural and economic factors relating to global change.

In September, Professor Morais left IGBP to take up a new position at the Research Cooperation Unit (FORSK) of the Swedish International Development Cooperation Agency (Sida).

A respected archaeologist, Professor Morais joined IGBP in 1995 from the Tropical Research Institute and the Lusophone University in Lisbon, Portugal, to forge links between social and natural sciences. Originally from Mozambique, he worked tirelessly to spearhead a drive to develop global-change national committees throughout Africa, Europe, Asia and the Americas. This blossomed into a powerful internationally coordinated research network.

Many of the key intellectual developments in Earth-system science emerged during Professor Morais's period with IGBP. Indeed, he can take considerable credit for positioning socio-economic considerations at the centre of global-change research coordinated by IGBP.

In 1996, the archaeologist took a nascent programme on human dimensions and helped shape it into the International Human Dimensions Programme on Global Environmental Change.

Through developing and participating in landmark events such as the 2001 conference in Amsterdam and the Dahlem workshop on civilisations and the environment, Professor Morais was instrumental in steering IGBP towards developing the Integrated History and Future of People on Earth (IHOPE) project.

More recently, Professor Morais had a key role in creating the trans-disciplinary agenda for the Planet Under Pressure conference and raising funds to support the attendance of hundreds of scientists from the developing world.

On his time at IGBP, Professor Morais said, "It has been a joyful journey; I will particularly miss kindred spirits throughout IGBP and throughout the world."

"I witnessed IGBP performing best when overcoming knowledge fragmentation and regional divides," he added. "I believe the challenge ahead is to expand on both quantitative and normative knowledge – what it is to be human and valued in the Anthropocene – to better understand socio-cultural mindsets and seek solutions that transcend disciplinary biases, language and culture."

He remarked that to achieve this IGBP and partners must evolve to truly represent universal collaboration across countries and regions.

During his long career at IGBP Professor Morais embodied this vision. He has been a valued colleague and critical strategic thinker within IGBP. His wisdom, warm personality and truly global perspective will be missed.

## Iconic synthesis now freely available

FOR those scouring Earth for evidence we have entered a new geological epoch – the Anthropocene – look no further than between the covers of IGBP's iconic first synthesis, *Global Change and the Earth System: A Planet Under Pressure* (Steffen *et al.* 2004). For the first time, this meticulous and detailed tome is available to download freely.

*Global Change and the Earth System's* 336 pages capture the state of the planet and the pressure it is now under. The synthesis contains a collection of 24 graphs that have become known as the "Great Acceleration". Twelve graphs show how the global economic engine has exploded in size in the last 60 years. The next 12 graphs show how this has directly influenced the geosphere and biosphere. These graphs have appeared in thousands of presentations relating to global change and the Anthropocene, most recently at the opening of the Rio+20 summit and in a presentation to the Dalai Lama.

Now, as IGBP embarks on synthesising its second phase, the contract with the book's publisher, Springer, has expired allowing IGBP to make it freely available.

The publication, a culmination of 15 years' work by thousands of scientists worldwide, was the pinnacle of IGBP's first phase.

The synthesis led to the emergence of five landmark concepts in Earth-system research.

First, the notion that Earth is an interconnected system with humans as an integral part.

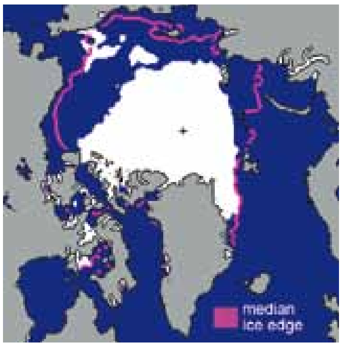
Second, the unprecedented spurt in human activity beginning around the middle of the last century – the "Great Acceleration" – accompanied by significant changes in the biophysical Earth system.

Third, the Anthropocene: humans have become the prime driver of change on the planet, pushing it into what might be a new geological epoch.

Fourth, the possibility of crossing irreversible thresholds in the Earth system. The combined impact of human societies risks major long-term global change with potentially deleterious consequences for humanity.

And finally, the need for and possibility of planetary stewardship in a rapidly changing world. The final chapter argues that "global sustainability" is for the benefit of all societies, a sentiment echoed in the close of the preface, which ends, "A truly global system of science is needed for coping with the challenges that lie ahead."

See www.igbp.net




National Snow & Ice Data Center

## Arctic sea ice: record low

IT IS official. This summer Arctic sea ice covered an area smaller than the previous low recorded in the summer of 2007. Notwithstanding annual variability, the extent of summer sea ice has been declining since satellite observations began in 1979, a trend that is particularly pronounced during the past decade or so.

In part, the rapid melting during August could be attributed to the effects of a strong cyclone. But ice continued to be lost at a fair clip even after the cyclone. Temperatures in the region have not been exceptionally high this summer, unlike in 2007. This points to the role of another factor: multi-year ice.

A feature of the last few years has been the increased loss of old, multi-year ice. In normal circumstances, such ice tends to survive summer melting. Continued warming, though, has taken its toll. New ice that forms during the winter is less able to survive the following summer.

Additional information: http://nsidc.org/arcticseaicenews/

See also page 8 of this issue.

## Climate chemistry

THE FIFTH phase of the Coupled Model Intercomparison Project (CMIP5) seeks to compare a suite of models to test their ability to reproduce past climate and project future climate change. The exercise focuses on $CO_2$, but will not explore in detail a key source of variability in model results – short-lived climate forcers. The role of such forcers, including aerosols and tropospheric ozone, is instead being investigated by an effort co-sponsored by IGBP's IGAC project.

The Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP) includes most of the models used by CMIP5. It aims to uncover atmospheric compositional changes and their effects on radiative forcing between 1850 and 2100. To this end, it is making use of the growing number of observations of atmospheric composition provided by various satellite- and ground-based instruments. These observations will be used to test the results of climate models.

Shindell *et al.* report that the reduced air pollution in North America and Europe is more than compensated by increases in Asia. As a result, the cooling effect of aerosols has probably ameliorated the warming induced by greenhouse gases during recent years. Young *et al.* find that tropospheric ozone concentrations will be lower in the year 2100 as compared to the year 2000, except for the scenario that posits the highest future temperature increase.

These and other results are now available for review in a special issue of *Atmospheric Chemistry and Physics Discussions*.

http://www.atmos-chem-phys-discuss.net/special_issue176.html

# OCEAN ACIDIFICATION: PRESENT BEATS PAST

THE OCEANS may be acidifying faster today than they did in the last 300 million years, according to research published in the journal *Science* in March this year. The results are based on a workshop organised by IGBP's PAGES project.

In a review of hundreds of paleoceanographic studies, the researchers found evidence for only one interval in the last 300 million years when the oceans changed as fast as today: the Palaeocene-Eocene Thermal Maximum, or PETM. About 56 million years ago, a mysterious surge of carbon into the atmosphere warmed the planet and turned the oceans corrosive. As many as half of all species of benthic foraminifera, a group of unicellular organisms that live at the ocean bottom, went extinct, which probably affected deep-sea organisms higher up in the food chain. The measure of ocean acidity – its pH – may have fallen as much as 0.45 units.

"These scientists have synthesised and evaluated evidence far back in Earth's history," said Candace Major, Program Officer in the National Science Foundation's (NSF) Division of Ocean Sciences, which funded the research. "The ocean acidification we're seeing today is unprecedented," said Major, "even when viewed through the lens of the past 300 million years, a result of the very fast rates at which we're changing the chemistry of the atmosphere and oceans."

In the last hundred years, rising carbon dioxide from human activities has lowered ocean pH by 0.1 unit, an acidification rate at least ten times faster than 56 million years ago, says Bärbel Hönisch, the study's lead author. The Intergovernmental Panel on Climate Change (IPCC) predicts that pH will fall another 0.2 units by 2100, raising the possibility that we may soon see ocean changes similar to those observed during the PETM.

Ocean acidification was the theme of a major conference last month in Monterey, California, organised by IGBP, the Scientific Committee on Oceanic Research and the Intergovernmental Oceanographic Commission.

Hönisch B *et al.* (2012). *Science* 335: 1058-1063, doi: 10.1126/science.1208277.

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# A silver lining to ARCTIC CLOUDS?

The relentless increase in summer sea-ice melt is likely to amplify Arctic warming. But could the same conditions also spur the activity of marine microbiota, increase cloudiness and counteract the melting? **Paty Matrai** and **Caroline Leck** explore.

Kevin Arrigo and colleagues reported recently in *Science* that in July last year, phytoplankton had bloomed strongly beneath Arctic pack ice of the Chukchi Sea. So lush was the bloom that Paula Bontempi, NASA's Ocean Biology and Biogeochemistry Program Manager, likened it to finding the "Amazon rainforest in the middle of the Mojave Desert." Like any plant, the unicellular marine phytoplankton need light to thrive. Old, thick sea ice, especially when covered with snow, is opaque but thinner ice underlying melt ponds is more transparent, and it is under such ice that the blooms reported by Arrigo *et al.* occurred. We know such blooms have occurred before: but, as the Arctic continues to warm faster than any other region on Earth, we can expect them more frequently. In fact, phytoplankton and other marine micro-organisms could ultimately help counter the rapid warming. To find out how, we will need to stick our heads into the Arctic clouds.

The ever-shrinking area of summer sea ice is one of the most visible manifestations of Arctic climate change. This summer, ice cover melted to its lowest extent in the satellite record, breaking the previous record low observed in 2007. If this trend continues, the region is likely to witness ice-free summers in the near future. Sea ice reflects incoming solar radiation, but the open ocean absorbs and stores solar radiation during the summer. Later, during the autumn, this heat is released and further warms the atmosphere. As more ocean is exposed, a positive feedback loop develops accelerating summer sea-ice melt – attested to by observations in the past decade.

**We will need to stick our heads into the Arctic clouds.**

But low-level clouds, which also control the Arctic surface radiation balance, could potentially slow down or even reverse the warming. For most of the summer, such clouds tend to warm the surface. But during the peak-melt season at the end of the summer, the right type of low-level clouds (see Box) could cool the surface and thereby influence the timing of the autumn freeze-up. Earlier freeze-up will cause thicker ice that might melt less during the following summer, surviving into the subsequent winter. If such a process were to recur over several years, it could delay or even prevent sea ice from melting completely during the Arctic summer. In other words, it would constitute a negative feedback.

What are the odds of a negative feedback loop developing? To answer this question we need to know, among other things, what controls the optical properties of Arctic low-level clouds and how they would change in a warming climate. The Arctic's inaccessibility ensures that data remain sparse, and our understanding of the complex relationship between the clouds, sea ice, ocean and atmosphere is still evolving. But the situation is improving. In particular, we are beginning to get a handle on the sources of the small atmospheric particles – cloud condensation nuclei (CCN; see Box) – that eventually spawn clouds. We now know that the greatest number comes from marine micro-organisms (Leck and Bigg 2005a; Orellana *et al.* 2011). How such organisms respond to the melting sea ice, whether in ways reported by Arrigo *et al.* or in other ways, will thus strongly


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influence cloud formation and their optical properties, and perhaps the rate of future melting.

## Seeding clouds with microgels

Marine microbial food webs produce a gas called dimethyl sulphide (DMS), which is released to the atmosphere from the uppermost ocean. There, it oxidises to form various intermediate products and ultimately sulphate particles. In 1987, Robert J Charlson and colleagues reviewed existing evidence to implicate DMS in the production of oceanic CCN. Thus was born the CLAW hypothesis, named so informally after the paper's authors (Charlson, Lovelock, Andreae and Warren). This provocative hypothesis posits that in the marine realm, DMS emissions would trigger cloud formation, which would cool the ocean surface. This would in turn affect further emissions of DMS by changing the speciation/abundance of marine phytoplankton, leading to a feedback loop.

Observations in the early 1990s from the Arctic did indeed show that the intermediate oxidation products provided most of the mass for the CCN-sized particles observed over pack ice (Leck and Persson 1996). The source of most of the DMS, though, was at the fringe of the central Arctic Ocean, just around the hospitable edges of the pack ice. At that time, this suggested that winds carried DMS-rich air towards the North Pole, and oxidation of the DMS led to extremely small sulphuric acid particles. Theoretically, these particles would then grow slowly by further condensation of the acids until they were large enough to serve as CCN.

Surprisingly, it turns out, sulphuric acid had nothing to do with the small precursors of CCN. Observations from the Arctic in the mid-1990s instead showed that these small precursors are mostly five or six-sided insoluble solids (polymers) resembling viruses or microcolloids. Subsequently, researchers detected large numbers of similar particles within the thin surface film at the water-air interface between ice floes. These are often aggregated into <100-nanometre-diameter compact balls, assembled as microgels bound by calcium atoms. The microgels are networks of polymer filaments, only a few nanometres in size, made up of polysaccharides or sugars. In 2011, researchers confirmed that the particles found in the atmosphere behave as microgels and originate in the water (Orellana *et al.* 2011) from the activity of sea-ice algae, phytoplankton and, perhaps, bacteria.

Across the central Arctic Ocean, the ubiquitous diatoms *Melosira arctica* and *Fragilaryopsis cylindrus* are known for surrounding their cells with polymeric substances, suggesting an important role for them in the production of polymers. Microgels have the right properties to act as nuclei for clouds. Furthermore, they could also provide sites for condensation of the oxidation products of DMS. In 2005, Leck and Bigg tested predominantly airborne sulphate particles for the presence of microgels. They detected water-insoluble marine microgel material in half or more of their samples. The co-occurrence of atmospheric organic material and biologically active marine waters has been confirmed for the high Arctic waters, and has also been documented for temperate waters (Faccini *et al.* 2008, Russell *et al.* 2010). But the universality of such microgels, both in the coastal and open-water regions of the Arctic Ocean and at lower latitude oceans, has not yet been confirmed.

**Microgels have the right properties to act as nuclei for clouds.**

## Beyond the CLAW

Observations from the Arctic question the key role attributed to DMS in the CLAW hypothesis (Leck and Bigg 2007). In the emerging picture of the Arctic atmosphere, DMS concentration will determine the mass of the particles by producing material for their growth. But it is the

### Getting the clouds right

Clouds, which come in all shapes and sizes, form when water vapour condenses. But vapour needs something to condense on – tiny airborne aerosol particles known as cloud condensation nuclei (CCN). Typically, CCN are about 100 nanometres in diameter. Depending on their properties and heights, clouds can either warm the surface by triggering a localised greenhouse effect or cool it by reflecting solar radiation.

If CCN are scarce, the resulting clouds will contain fewer and larger droplets. Such clouds will reflect little sunlight to space while blocking the escape of heat from Earth's surface, causing it to warm. However, if CCN are plentiful, many fine droplets form and the resultant clouds are better reflectors, which can cool the surface below.

Anthropogenic particles are virtually absent in the summer over the central Arctic, north of latitude 80°N. This "clean" air, with few CCN, makes the summer low-level clouds optically thin, with fewer but larger droplets: a heat trap. But if Arctic warming spurs the activity of microbiota, organic sources of CCN might become more prominent and lead to more reflecting clouds.

number of airborne microgels that will primarily influence the number of CCN and the resulting optical properties of the cloud droplets. Indeed, research during the past two decades – reviewed last year in *Nature* (Quinn and Bates 2011) – does not corroborate the CLAW hypothesis for other regions as well. But this does not rule out a link between marine micro-organisms and climate, especially on a regional scale. From that perspective, the Arctic observations discussed here could provide a more nuanced link between marine biology, cloud properties and climate.

The Arctic low-level clouds have a pronounced influence on the surface energy budget. In summer, a scarcity of CCN leads to optically thin clouds. The sources of these CCN are mostly located along the marginal ice zone and north thereof towards the pole. Marine micro-organisms are the primary contributors to CCN, and hence an important control on the optical properties. Their response to the changing Arctic climate is thus key to a possible negative feedback that would slow down the melting of summer sea ice. We know that the immobile ice algae as well as the floating phytoplankton are likely to be strongly affected by changing sea-ice conditions (Wassman and Reigstad 2011). But whereas both generate dissolved organic matter and are hence a potential source of airborne microgels, their relative importance is not fully understood.

The recent report of a sub-ice phytoplankton bloom by Arrigo and colleagues, in conjunction with previous and current observations, strongly suggest increased activity as the Arctic warms. If they are found to be a strong contributor of microgels, phytoplankton might facilitate an enhanced reflectivity of the low-level clouds that help counteract increased ice melt.

The melting of sea ice might reduce or even eliminate the habitat of ice algae. And it might have indirect effects. The presence of sea ice has prevented, or significantly controlled, wind-driven mixing of the surface layer of the Arctic Ocean. This has kept the floating phytoplankton mostly at the surface. Thinner ice or more open ocean areas would allow the wind to stir the surface ocean, deepen or break the mixed layer, thereby reducing algal growth. If organic matter derived from ice algae was confirmed to be a major source of the microgels throughout the Arctic, future warming might imply reduced supply of CCN and thus very optically thin clouds with enhanced surface warming. On the other hand, ice formation during freeze-up excludes salt brine and other substances, including dissolved organic matter likely assembled as gels. These gels can end up in both the surrounding water and the atmosphere during this crucial period.

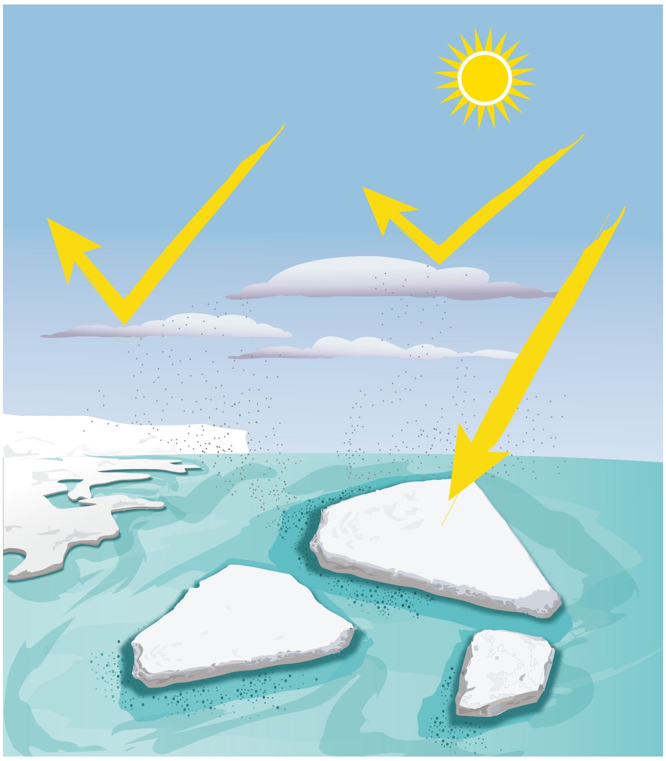

Figure 1. Schematic sketch (not to scale) depicting the negative feedback. Melting sea ice spurs the activity of marine microbiota, thereby increasing the availability of the polymeric sugar precursors (grey dots) of CCN. The low-level clouds thus formed reflect some of the incoming solar radiation and cause surface cooling. This process can hasten the autumn freeze-up.

**But this does not rule out a link between marine micro-organisms and climate.**

Clearly, there are too many unknowns at this stage to fully assess the likelihood of a negative feedback involving micro-organisms and clouds. But given how sensitive the Arctic is to climate change and how important it is for the regional and global radiation balance, there is a strong rationale for continued research to test this hypothesis. ▮

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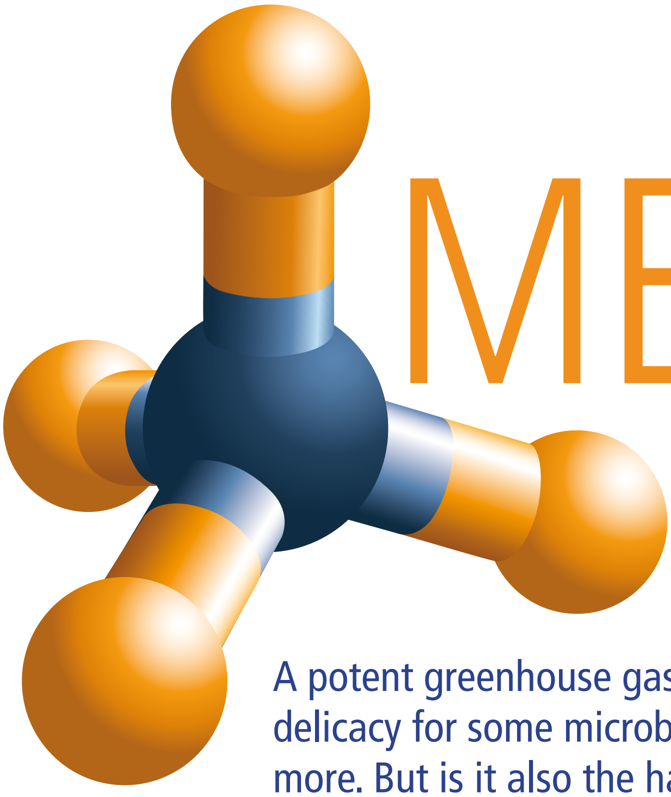


# METHANE

## NOT A DAMP SQUIB, NOT YET A TIME BOMB

A potent greenhouse gas, an energy source, a culinary delicacy for some microbes – methane is all of these and more. But is it also the harbinger of impending catastrophe? There's no smoking gun, finds **Ninad Bondre.**

About 55 million years ago, at the beginning of the Eocene epoch, the planet experienced a hot flash that was to last for over 100 millennia. The finger of suspicion points to a dramatic perturbation of Earth's carbon cycle. What sustained the warming, many researchers say, were massive methane emissions from ice-like compounds called methane hydrates (or clathrates). Such compounds are normally stabilised in marine sediments or beneath frozen ground onshore. During the earliest Eocene, something – and we don't know what exactly – destabilised the hydrates, releasing prodigious quantities of methane.

As a greenhouse gas, methane is rather potent, but it lasts in the atmosphere for only about a decade before oxidising to carbon dioxide. A sudden large release or a more subdued but continuous release of methane would strengthen the greenhouse effect and warm the Earth's surface. This could, in turn, put in motion processes that reinforce the warming (Figure 1). As the saga of the Anthropocene unfolds, the stability of methane hydrates and other methane sources is back in focus, as is the potential for a giant methane outburst. Unlike the earliest Eocene, we know well what the modern trigger might be: Arctic warming.

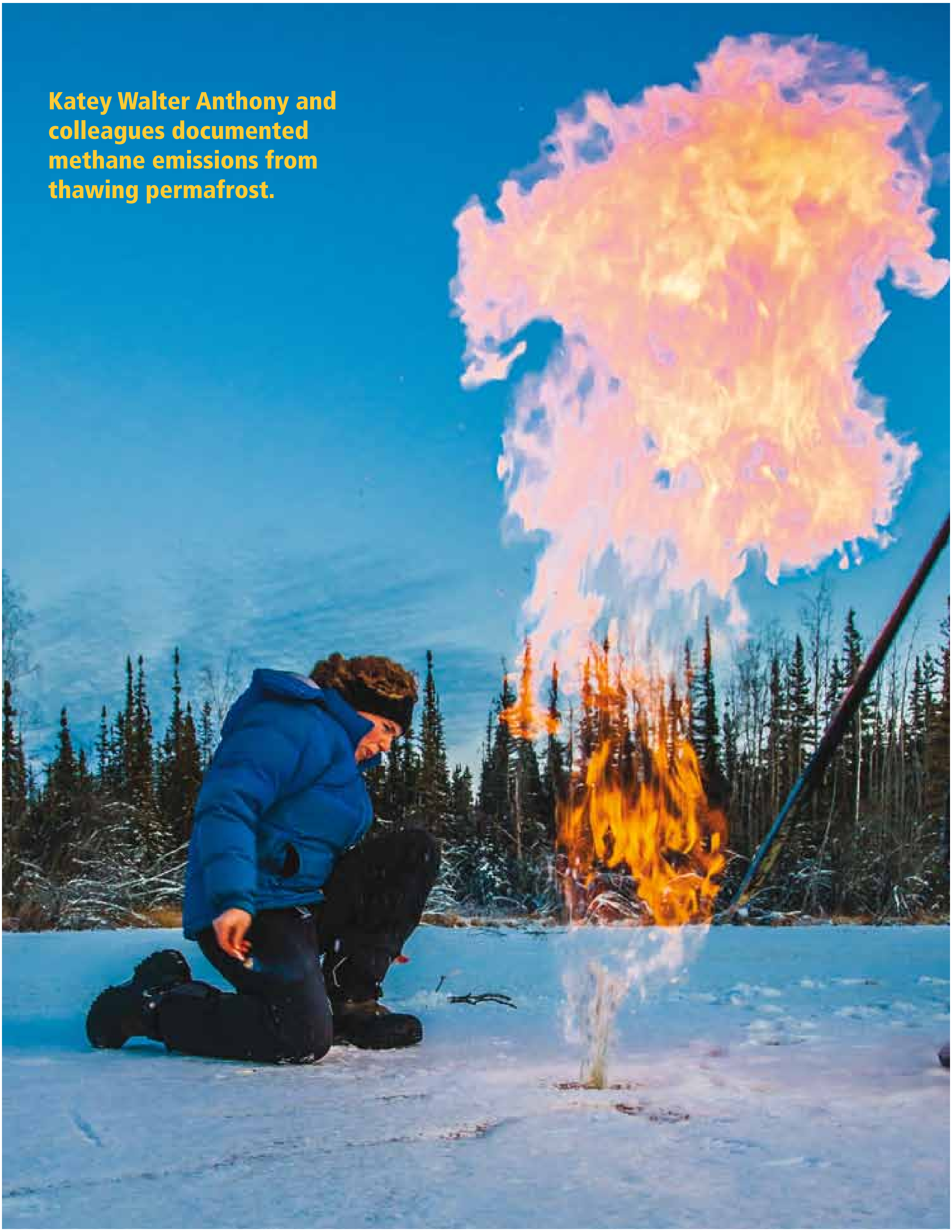
**As a greenhouse gas, methane is rather potent.**

In recent years, a number of scientific and popular articles and blogs have explored the consequences of catastrophic methane release. Attempts to calm the nerves have so far done little to quell the unease. Arctic sea-ice extent this summer was the lowest in the satellite era, a fact that will only add to the unease. The Arctic Methane Emergency Group, for example, perceives the situation to be dire enough to call for urgent measures to cool the Arctic. A slew of possible geoengineering solutions – from cloud removal to injecting aerosols into the atmosphere – have been proposed as candidates to deal with an emergency.

### The Arctic connection

Hydrates form when methane gas and water combine at low temperature and moderate pressure, conditions most likely to occur several hundred metres beneath water and/or sediments. The methane itself results from the microbial decomposition or deep burial and/or heating of organic matter. The amount of hydrates stored in the Arctic region is not well constrained but is estimated to be on the order of several hundred billion tons of carbon and possibly more. These occur in deep marine sediments, on the continental slopes and beneath the permafrost on land. They also occur beneath the remnant permafrost on shallow continental shelves that have been flooded during the past 15,000 years of sea-level rise. Hydrates in the deep marine sediments are not considered to pose a risk for at least the coming hundreds of years.

Until recently, the permafrost onshore and on continental shelves was thought to serve as a fairly effective seal. So much so




University of Alaska Fairbanks/Todd Paris.

that hydrates in the underlying sediments received little attention in discussions of the modern methane cycle. Indeed, methane from hydrates probably makes up a very small fraction of the current atmospheric concentration of about 1800 parts per billion of methane. But recent observations from the remote East Siberian Arctic Shelf (ESAS) by Irina Shakhova and colleagues point to perforations in the seal. In a 2010 *Science* paper, the researchers reported the widespread release of methane from marine sediments to the overlying ocean water and atmosphere. More recently, Shakhova's research group presented the findings of its latest fieldwork at two major conferences, drawing attention to even more extensive releases.

The ESAS was once a frozen tundra landscape that was gradually submerged as sea levels rose at the end of the last ice age. For thousands of years, it has been exposed to conditions very different from those under which it formed. Shakhova and colleagues contend that this has made it more susceptible to recent warming; it is now beginning to thaw. The warming would probably accelerate if the relentless decline of summer sea ice were to continue (see page 8 of this issue). At the moment, though, it remains unclear how long the region has been emitting methane at the rates reported recently. The link between Arctic warming and the observed release is yet to be firmly established. We also do not have a good handle on how the emissions will respond to future climate change.

Hydrates are not the only source of methane in the region. Walter Anthony *et al.* reported in *Nature Geoscience* this year that methane is leaking out of thawing permafrost and regions of glacial retreat throughout Alaska. Unlike the ESAS, this is gas that had accumulated over time – originating from a range of sources including decomposing organic matter, hydrocarbons and perhaps hydrates – but had hitherto been corked by ice or frozen soil. The scientists noted that the most active sites emitting old methane occur in areas of continuous permafrost with locally increased permeability or in areas that have only recently lost their capping ice. Continued warming could pop the cork, leading to a relatively rapid but transient pulse of methane emission to the atmosphere.

**Hydrates are not the only source of methane in the region.**

It is useful to compare the methane emissions from these recent studies with global emissions (from all sources). Shakhova *et al.* reported an annual value of about 8 million tons for the ESAS. Walter Anthony's group estimated an annual value of up to 2 million tons for the circumpolar permafrost based on their observations in Alaska. Together, the emissions are a significant but small fraction of the annual global value, which is on the order of 500 million tons (of which the anthropogenic component is approximately 60 percent). Tropical wetlands, agriculture and fossil-fuel production and consumption are much bigger players. The contribution from the Arctic region could conceivably increase as the region warms, but does the warming constitute a clear and present danger?

## Assessing the risk

Shakhova and colleagues find the formation of large pockets of free methane gas in the ESAS region feasible; these could conceivably lead to near-instantaneous methane release. Oxidation by anaerobic microbes within sea water can consume a lot of methane that does bubble out, although this process would be rather inefficient in the shallow water depths associated with the ESAS. But Carolyn Ruppel, who heads the United States Geological Survey's Gas Hydrates Project, cautions against inferring massive methane escape to the atmosphere based on seawater methane concentrations collected at different times. She also notes that researchers currently lack a technique that can distinguish between methane recently released from gas hydrate and other methane sources. Thus, it is not yet possible to discern whether the elevated methane levels detected on the ESAS imply methane hydrate dissociation.

Ruppel's calculations show that an instantaneous methane release equivalent to about 2 billion tons of carbon could bump up the atmospheric concentrations of the gas by over 55 percent of its current value. But such a release requires a major destabilisation, for example that triggered by a submarine landslide. Even if a billion tons of carbon were to be released suddenly as methane, David Archer notes on the RealClimate blog that the effect on temperature would be akin to that of a major volcanic eruption – except, of course, that a methane release would cause warming instead of cooling. Assuming that this would be an isolated incident, the warming would be relatively short-lived given the atmospheric residence time of about a decade for methane. The risk of crossing a dangerous threshold was the subject of an extended discussion on Andy Revkin's Dot Earth blog on The New York Times site last year. Several scientists expressed the view that a catastrophic methane outburst arising from hydrate instability in the Arctic was rather unlikely in the near term.

Many researchers do agree that the northern latitudes will witness smaller but regular releases of methane as the region warms. As methane ultimately oxidises to $CO_2$ in the atmosphere, it will add to the atmospheric $CO_2$ concentrations and thus amplify the greenhouse effect in the long term. What this will do to the huge pool of carbon in the permafrost – currently

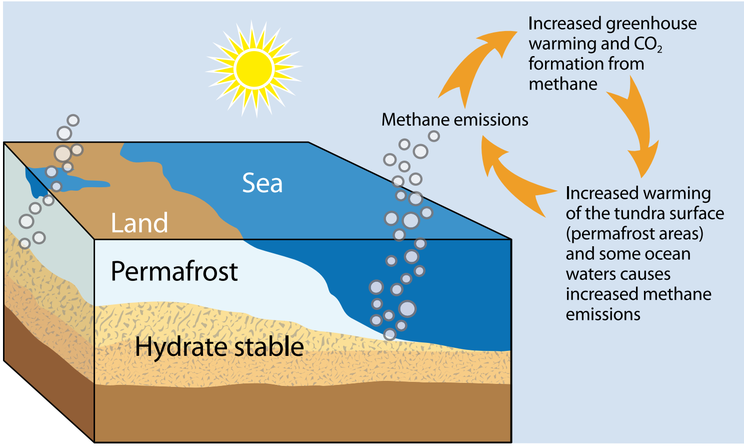



Figure 1. Schematic sketch (not to scale) depicting the Arctic methane feedback. Pronounced regional warming increases methane emissions, which strengthen the greenhouse effect and warm the surface. The warming, in turn, triggers additional emissions. Modified after Figure 4 from Ruppel C and Noserale D (2012).

www.usgs.gov/blogs/features/usgs_science_pick/gas-hydrates-and-climate-warming/ (Accessed on 15 September 2012.)

sequestered as frozen organic matter – is another story.

Despite what appears to be a consensus against catastrophe, at least in the short term, the fascination with methane in the popular media and blogs suggest undercurrents of concern. The perceived vulnerability of the large ESAS methane hydrate deposits and the potential for unanticipated disturbances seem to be a big factor behind the unease. Does the recent geological past – the last million years or so – tell any tales that could help steer this discussion? I put this question to Hubertus Fischer, a palaeoclimate researcher at the University of Bern and a co-chair of IGBP's Past Global Changes project. Fischer says it is instructive to look at methane variations during the last glacial period as well as the overall variation during the last eight interglacials.

The last glacial period was marked by several abrupt temperature increases – the Dansgaard-Oeschger (DO) events – during which the atmospheric concentrations of methane spiked. Previous work shows that the hydrogen-isotopic signature of this methane is unlike that expected for deep marine hydrates (for example, Bock *et al.* 2010). There could be a contribution of such hydrates towards the end of the DO events, but no indication of a catastrophic release. Fischer notes that methane released from shallower hydrates, such as those on the ESAS, would not have a unique hydrogen isotopic signature. As discussed earlier such hydrates underlie permafrost that is flooded during interglacial sea-level rise. But the sea level was low at the beginning of the DO events and rose by only 20 metres or so during the events, not sufficient to flood large areas of permafrost and prime them for methane release during future events.

Interglacials refer to the geologically brief, warmer periods between ice ages. They are characterised by high atmospheric concentrations of greenhouse gases. Two of the last eight interglacials were significantly warmer than the Holocene and also about 2°C warmer than the present. In the Arctic the temperature was likely even higher. Nevertheless, Fischer points out, the methane concentrations reconstructed for the past interglacials are remarkably similar. This suggests that although methane sources (organic carbon in permafrost and methane hydrates, for example) respond during transitions to the warmer periods, emissions quickly stabilise. Thus, the rate of warming is more important than the overall temperature increase to assess future methane release from permafrost. It should be noted that many of the future warming scenarios easily exceed the amplitude – but more importantly also the rate – of warming leading up to and during the last interglacial.

**The lessons that the past offers us are instructive but incomplete.**

The lessons that the past offers us are instructive but incomplete, and it is to models we must turn to project and predict future changes. Fischer emphasises that such models are still at an early stage, not least because there are too few observations and limited understanding of methane emissions at the ecosystem scale. Slowly but surely, though, the observations are beginning to build up. The field campaigns undertaken by the teams of Shakhova, Walter Anthony and others, coupled with remote sensing studies as discussed on page 26 of this issue, are steps in the right direction.

The scientific information at hand gives no indication of a catastrophe waiting to happen. But it does highlight gaps in our understanding and points to the need for continuous monitoring of changes to the methane cycle as the Arctic region warms. ▮

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A new way of analysing complex global challenges – DebateGraph – has caught the attention of the White House, the UK Prime Minister's Office and CNN. Here, DebateGraph co-creater **David Price** discusses how "collaborative argument visualisation" can help to support a planet under pressure.

# Mapping a PLANET UNDER PRESSURE

If true character is revealed in the choices made under pressure, the early decades of the 21st century promise to be revelatory for our species.

As the *State of the Planet Declaration*[1] notes:

> *Research now demonstrates that the continued functioning of the Earth system as it has supported the well-being of human civilization in recent centuries is at risk. Without urgent action, we could face threats to water, food, biodiversity and other critical resources: these threats risk intensifying economic, ecological and social crises, creating the potential for a humanitarian emergency on a global scale. In one lifetime our increasingly interconnected and interdependent economic, social, cultural and political systems have come to place pressures on the environment that may cause fundamental changes in the Earth system and move us beyond safe natural boundaries.*

**The existing patterns of interaction leave much to be desired.**

Yet, in the jaded aftermath of the UN's Rio+20 conference, it's clear that scientific insight into the emerging systemic pressures isn't a sufficient condition for action – and that our jumbled, planetary bundle of individual and institutional interests has a momentum that's hard to deflect.

## So, what next?

If the goal is to accelerate societal learning, the interplay between scientists, policy-makers and the wider public will be critical. However, the existing patterns of interaction leave much to be desired.

First, the science-policy relationship is often difficult and dysfunctional[2].

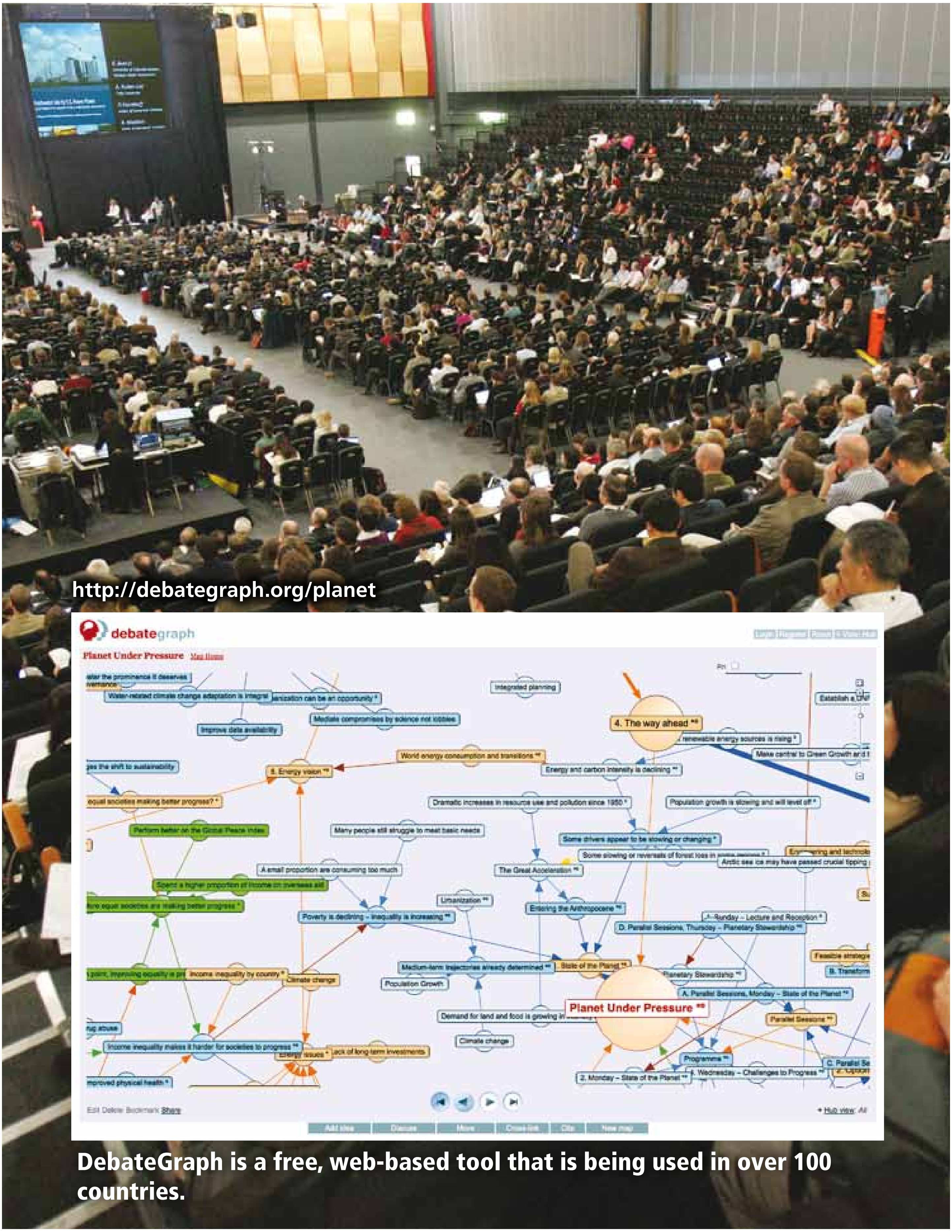
Second, the international governance infrastructure – the United Nations, World Bank, WTO and others – was designed to meet the needs of the post-WWII era and is ill-adapted to the interconnected and transdisciplinary challenges it now faces.

And finally, our main public communication channels seem better attuned to the linear and polarised narrative of crisis than to the nuanced, detailed, anticipatory work of crisis avoidance or minimisation.

Quite simply, among other changes[3], we need to find new ways to communicate the kinds of global challenges that elude compression into a simple linear narrative.

News cartography – the creation of dynamic, interactive, collaboratively editable and shareable maps of the stories – is a promising, early-stage response to this challenge. It gives people a way to pull apart an issue like food security or ocean acidification, sift fact from fiction and get to the essence of the debate. It enables everyone to explore a topic at their own speed and find out who is saying what. How much do we know with certainty? How reliable is the information? Who disagrees? What are the solutions?

DebateGraph[4], the website that I co-founded with the former




DebateGraph is a free, web-based tool that is being used in over 100 countries.

Photo: Philip Wade Photography

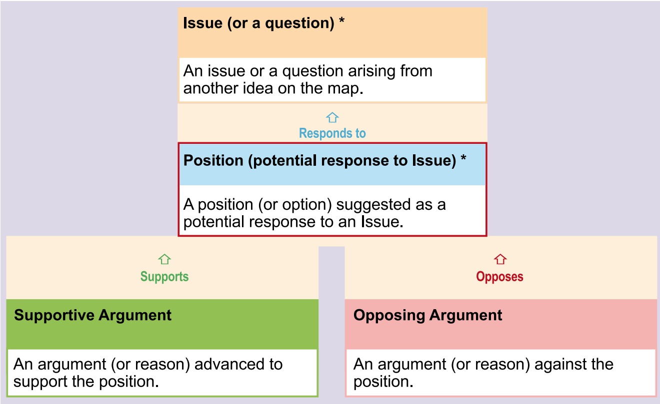


Figure 2: The basic building blocks of a map.

Australian Minister for Higher Education, Peter Baldwin, is one of the pioneers in this new field. We created it as a social-entrepeneurial response to our shared frustration at the limitations of public dialogue on public policy topics.

The free, web-based tool is being used in over 100 countries, and in many different fields, from education, health, strategy, media, publishing, environment, conflict resolution, conferences, and group facilitation to public consultation and planning. Our collaborative partners so far have included: the White House Office of Science and Technology Policy (on open government), the UK Prime Minister's Office (on media policy), CNN (the Amanpour series) and the European Commission (on the governance of Europe's Digital Agenda) – and high-profile public maps have now received over a million views.

The New York Times picked up on our most recent experiment, the Planet Under Pressure DebateGraph, which we are developing with the Earth System Science Partnership (ESSP), IGBP and the Future Earth team, along with a group of doctoral students at the Dutch institute SENSE (Research School for Socio-Economic and Natural Sciences of the Environment)[5].

Planet Under Pressure gathered leading scientists, policymakers, NGOs and businesses to explore how the scientific community can develop and share the knowledge necessary to identify the risks humanity faces in the Anthropocene and respond wisely to the policy choices this presents. This is the ultimate complex, interconnected topic; so it's a perfect test-bed for DebateGraph.

**Visual cues identify the ideas with largest support.**

The live work-in-progress on the map (Figure 1) is available openly online and you are welcome to join and contribute to the evolving debate[6].

The basic process is simple. DebateGraph creates reasoned pathways through complex problems by: 1) breaking down the subject under discussion into discrete ideas; 2) figuring out the relationships between those ideas; 3) expressing the ideas and relationships visually; and 4) reiterating steps 1-3 to improve the map as the understanding of all the participants develops.

In DebateGraph, ideas are either thought bubbles or boxes, with arrows expressing the relationships between the ideas, and bright colours signalling the types of ideas and relationships. Taken together, the viewer can digest the big picture at a glance.

The general example given in Figure 2 shows the set of core building blocks. An Issue or Question (orange) is raised. A potential response to that issue (or Position) appears in blue. Supportive (green) and Opposing (red) Arguments can appear that articulate the cases for and against Positions. Figure 3 illustrates how these building blocks have been applied in a small strand of the Planet Under Pressure map.

In Figure 3, a mapper has raised an orange Issue relating to the options for responding to the emerging planetary crisis. A blue option in response to the Issue has been proposed (widening the attack on greenhouse gases to include methane), and a green supportive reason has been offered in favour of this proposal – that reducing the methane in the atmosphere will make it easier for forests and land vegetation to absorb more carbon.

While DebateGraph offers a wide palette of idea types and relationships – including causality, consistency and formal logic – the core dialogic triad described above (of Issues, Positions, and Supportive and Opposing Arguments) can be combined multiple times to build large, comprehensive maps.

The structure of the map is augmented with embedded videos, images, charts, tables, detailed text, documents, files, citations and comments. Ideas can be cross-linked to other ideas on the same or different maps. All members of the community can add new ideas and edit and rate existing ideas. Visual cues identify the ideas with largest support. The system can fire off RSS feeds and email alerts to keep everyone up to date as the map evolves.

Collaboratively editable maps of public policy issues of this kind enable everyone within a community to benefit from the thinking of everyone else in the community transparently, efficiently and effectively – and independently of the vested interests of any institution, including the commercial mass media.

The maps bring together all of the salient policy ideas and evidence distributed across a transdisciplinary community into a single, coherent, meaningful structure. Each idea is represented just once and in a form that is continuously and iteratively open to challenge, support and refinement by all members of the community. Large-scale, multi-dimensional maps can evolve from the first simple seed question until the map addresses every salient consideration and perspective.

Once an idea has been represented on the map, there is no need for it to be repeated;

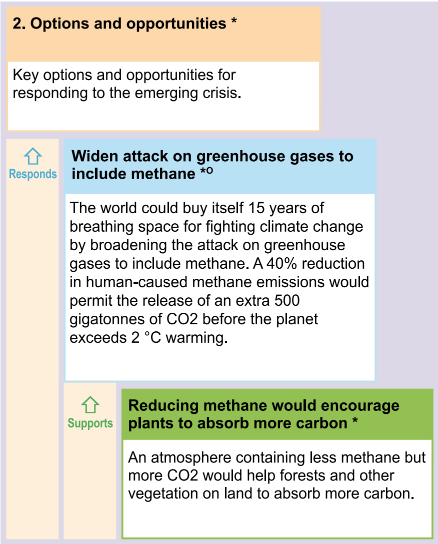



Figure 3: Building blocks as applied to a small strand of the Planet Under Pressure map.

instead the community is free to focus on improving, supporting, challenging and rating the idea.

In this way, collaborative visual mapping offers a powerful method for a globally distributed network of people to think through complex, non-linear and highly interrelated problems in a manner that is: cumulative (of new ideas and evidence); distillative (filtering out repetition, digression, *ad hominem* attacks etc); deliberative (allowing each point and strand of dialogue to be challenged, supported, clarified and evaluated); transparent (allowing everyone to see the underlying reasoning, and building participant and observer trust); multi-layered (connecting local issues to the regional to the national and the supranational and vice versa); and, always open to new participants and to new ideas, so that, as with science, the dialogue and understanding it generates become more rigorous as it evolves.

Externalising and structuring thought in this iterative form augments individual and group ability to think through complex issues. It helps the participants and readers to overcome the cognitive constraints of short-term memory and sub-optimal group processes such as groupthink and homophily. And it can do so in an often playful, creative and engaging way.

Just as a mediator seeks to create a physical space in which conflict can be explored and resolved, the interactive maps provide a networked context in which the conflicting values and interests of multiple stakeholders can be surfaced and addressed openly and in an explicitly reasoned way.

Sharing collective understanding in this structured and transparent form also helps each participant to see that his or her perspective has been heard and represented accurately in the appropriate context, which helps to build trust in the form and process of communication and ensure that the maps evolve towards a full and fair reflection of the subject under consideration.

Moreover, documenting the reasoning behind a community's thinking and decision-making helps to bring greater clarity and accountability to the community's analysis, choices and actions, and makes it easier for the community to learn from mistakes and improve its decision-making over time.

In principle, collaborative argument visualisation of this kind has the potential to enable a new kind of democratic public deliberation across existing disciplinary and institutional boundaries on a global scale – and, in due course, for that deliberation to enhance and guide the global policy governance process.

For now the technology and the Planet Under Pressure map remain in the early stages of development. We welcome help and feedback to push the technology and the map to their full potential, and to learn more about the social challenges of integrating an unconventional method into the core of the international policy-making dialogue.

**The interactive maps provide a networked context.**

The immediate next step for the Planet Under Pressure map is to keep refining and expanding the content to cover the outputs from Rio+20 and the Rio Dialogues, a process that all are welcome to join. In parallel with this, the project team will be presenting the map at conferences and symposia across the next 12 months.

If you are interested in learning more about the Planet Under Pressure mapping project, or embedding the map on your own blog or website, or if you would like to suggest other material to include in the map, do contact me and join the debate!

DAVID PRICE is the co-founder of DebateGraph and leads its consultancy, mapping and training projects. He lives in Somerset, UK.
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2. Sutherland W J *et al.* (2012) *PLoS ONE* 7(3): e31824, doi:10.1371/journal.pone.0031824.

3. Other promising developments, for example, include the emergence of the open science movement, the Rio Dialogues, and – building on the scientific advances of the GEC research programmes (IGBP, DIVERSITAS, IHDP and WCRP) and the ESSP – the transdisciplinary co-commitment of the Future Earth initiative.

4. http://debategraph.org

5. http://www.sense.nl

6. http://debategraph.org/planet

# A RIO RETROSPECTIVE



Media reports in Europe and North America were downbeat about the outcomes of Rio+20. But a more sober analysis points to some significant successes, not least for IGBP, reports **Owen Gaffney**.

The United Nations Conference on Sustainable Development – Rio+20 – attracted 50,000 people and 188 heads of state and ministers. Though no internationally binding agreements emerged, Rio+20 laid out the direction of international policy on global sustainability in the next decade and beyond. Its outcomes will have a direct bearing on the global-change research community as it steers towards the new ten-year initiative Future Earth: Research for global sustainability.

Rio was an ideal location to officially launch Future Earth. The summit provided a unique opportunity to engage a broad range of potential Future Earth stakeholders, from business and government, through to non-governmental organisations and UN departments.

Future Earth was a key part of the scientific community's input to Rio, but not the only one. An important goal for IGBP's engagement with Rio+20 was to provide an update on the scientific developments since the 1992 Earth Summit. For example, concepts such as the Anthropocene and the so-called Great Acceleration, which have emerged from IGBP research in the last ten years or so. As it turned out, the UN Secretary-General Ban Ki-moon opened the summit with a short speech and then introduced the film *Welcome to the Anthropocene* – co-produced by IGBP – to the assembled dignitaries. IGBP, the Anthropocene and Planet Under Pressure received prominent mention in his remarks.

**Rio+20 was an ideal location to officially launch Future Earth.**

IGBP's former Chair Carlos Nobre helped develop the programme of a week-long science and technology forum led by the International Council for Science (ICSU). Mercedes Bustamante (IGBP Scientific-Committee member) chaired a morning session dedicated to Earth-system research, which included talks by Professor Nobre and Chuluun Togtokh, Vice-chair of IGBP's Mongolian National Committee. The science forum made extensive use of the nine policy briefs and the *State of the Planet Declaration* published for Planet Under Pressure. In the same week, Professor Nobre wrote the lead editorial in the journal *Science* (15 June issue;) arguing that the development of Sustainable Development Goals, backed by sound science, offers the prospect of creating a more sustainable global society.

Much of the work to inform Rio+20 was done in advance, not least through the Planet Under Pressure conference. In April, IGBP Executive Director Sybil Seitzinger highlighted outcomes from Planet Under Pressure at a UN side event in New York during the final Rio+20 negotiations. This was one of three preliminary events organised by the UN to develop the Rio+20 agenda. IGBP participated in all these meetings.

The IGBP secretariat has been promoting the *State of the Planet Declaration* to the UN and national negotiators through UNESCO, ICSU and others. Indeed, over 1000 copies were distributed at Rio+20 by the IGBP regional office in Brazil. Several key recommendations arising from the global-change programmes and ICSU either made it into the final text of the outcomes document or have been taken forward independently by the UN Secretary-General.

For example, the outcomes document – entitled *The Future We Want* – includes the proposal from the global-change community to "strengthen the science-policy interface through review of documentation bringing together

dispersed information and assessments, including…a global sustainable development report" that builds on existing assessments.

This proposal could improve the fragmented science-policy landscape by tying together and building on the large existing assessments such as the Intergovernmental Panel on Climate Change (IPCC) and the new Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES). Such a new report could create strong policy links to Future Earth.

The global-change research community, through Planet Under Pressure, also proposed improving the international links between science and policy by creating a high-level, independent scientific advisory panel, possibly headed by a Chief Scientific Advisor reporting directly to the UN Secretary-General. Before Rio+20, Ban Ki-moon set up a small sub-committee led by UNESCO and including ICSU to develop this proposal. This committee has now met and proposed the establishment of such an advisory panel. In addition, the outcomes document includes a recommendation for scrapping the Commission for Sustainable Development and replacing it with a high-level Forum for Sustainable Development. This new forum would report to the General Assembly, and thus would operate at a much higher level than the Commission. It is envisaged any new assessment report would fall under the forum, which could provide a strong international policy platform for Future Earth.

As with all major events of this nature, the Rio+20 process was chaotic and at times unfathomable. The original "first-order draft" was weak on global-change science and the urgency to act, but it included much mention of science and technology and several firm proposals, such as the need for a new international research programme focusing on global sustainability. As the weeks dragged on and negotiators haggled over grammar it was clear this long and unwieldy document would never gain broad acceptance. Late in proceedings the draft was scrapped and a new document thrust on negotiators by Brazil and the UN. This was shorter and snappier and easier to agree. But significantly, much of the reference to science and technology had been wiped out, including the need for an international research programme on global sustainability.

This is a major issue. Had Future Earth been included in the final document there would be a strong political mandate for the initiative and, crucially, direct links to international policy on sustainable development for the next decade. Without this mandate, Future Earth is going to have to work a lot harder to ensure it is relevant and achieves its ten-year objectives for society.

**As with all major events of this nature, the Rio+20 process was chaotic.**

As many media have noted, the big-ticket, lasting legacy of Rio+20 is a commitment to develop a set of Sustainable Development Goals (SDGs). Although international agreements on climate and biodiversity have failed to gather traction during the past two decades, the Millennium Development Goals (MDGs) have caught the imagination of both the public and policymakers. By 2015, most countries will have made meaningful progress towards most of the goals, according to the economist Jeffery Sachs who spearheaded the MDG process from 2002 to 2006. Several goals will be met, including halving the number of people living in extreme poverty (though China's rapid economic growth takes the most credit for this achievement). But critics of the MDGs argue the goals were rushed through and not underpinned by the best available science.

In the next 18 months the new set of goals will be developed - in consultation with the scientific community. Indeed, the first science-policy workshop on the SDGs was at Planet Under Pressure, and the conference co-chair, UNESCO's Lidia Brito, is part of the team developing the science-policy interface for the goals. Close alignment with this process may help enumerate the policy implications of IGBP's forthcoming synthesis and provide an essential international science-policy interface for Future Earth. ▮

OWEN GAFFNEY is Director of Communications at the International Geosphere-Biosphere Programme.

# Earth-system science at a crossroads

**The Planet Under Pressure conference underscored a rapidly changing landscape of Earth-system science. Mike Raupach says that the path ahead should combine the need for wider engagement with a continuing commitment to reason.**

The Planet Under Pressure conference in London was the third major gathering of the Earth-system science community, following predecessors in Amsterdam (2001) and Beijing (2006). Each of these meetings has provided a chance to evaluate not only the latest science, but also the state of the Earth-system science community and its relationship with wider societies. The 2012 meeting indicated a community in rapid and sometimes difficult transition. Three major turning points can be discerned: fading optimism, the coupling between environmental and human wellbeing and science as a societal participant. Each of these has a double life, appearing both within the Earth-system science community and also in the wider world.

## Increasing urgency, decreasing optimism

Relative to its predecessors, Planet Under Pressure offered a sober-to-bleak assessment of the biophysical state of the planet and its ability to support the demands of a growing and increasingly affluent human population. Climate change, food security and water security were identified as the three leading pressure points among many.

**Planet Under Pressure marked the end of the era of naïve optimism.**

Bob Watson, who chaired IPCC during its third assessment in 2001, gave an assessment in his opening address that the world now has only a 50 percent chance of limiting warming to 3°C, and that the two-degree target agreed in Copenhagen in 2009 is impossible. His assessment was shared by many (including me[1]), both during and before the conference. Calculations suggest that keeping global warming below two degrees requires global emissions reductions at rates from 3 to over 10 percent per year, depending on assumptions about how quickly the trajectory of $CO_2$ emissions can make the U-turn from its present 3 percent per year growth to sustained reduction. The higher end of this range is probably unachievable technically, let alone politically.

This tone engendered a variety of responses throughout the conference, among different sessions according to focus and among different participants according to personality: desperation, urgency, resignation (as in Bob Watson's assessment) and, occasionally, withdrawal. Planet Under Pressure marked the end of the era of naïve optimism.

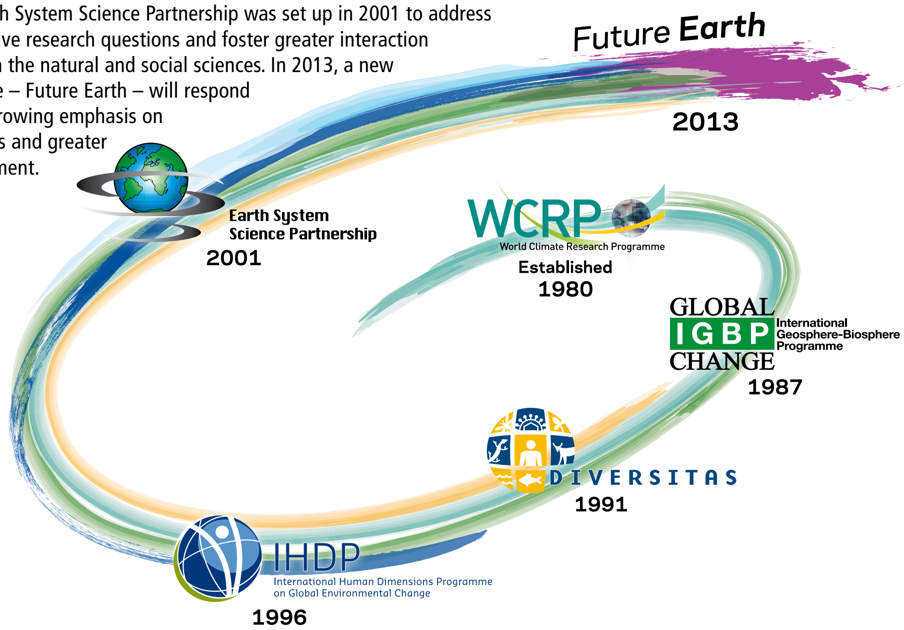
Although climate change is receiving the lion's share of public attention at the moment, other finite planet pressures are also of concern. In particular, food security and water security are immediate needs for human wellbeing. Both are issues with strong local texture, framed by global trends in population, affluence and trade. In the case of food, for example, there is evidence that yield improvements are slowing, global demand is intensifying and pressures from demand for biofuels are increasing prices for staples such as corn.

To an extent greater than for climate change, food and water security are predominant concerns for the geopolitical South. This leads to the second turning point.

## Environmental and human wellbeing as coupled issues

Planet Under Pressure was a more representative meeting than those in Amsterdam (2001) and Beijing (2006), in three ways. It came closer to gender balance than either of these predecessors; the human sciences had equal or greater representation, in both numbers and influence,

**The compact between Earth-system science and society is being reshaped. Hard work lies ahead to ensure that both partners are comfortable with the relationship.**




The Earth System Science Partnership was set up in 2001 to address integrative research questions and foster greater interaction between the natural and social sciences. In 2013, a new initiative – Future Earth – will respond to the growing emphasis on solutions and greater engagement.

relative to the natural sciences; and the voices of developing as well as developed nations were prominent. This led to an explicit focus on interactions between the geopolitical North and South.

Under the influence of these trends, environmental issues were framed at the conference both in biophysical terms and also as fundamentally human concerns. What are the consequences for human societies of seeing Earth not only as materially finite and ecologically vulnerable, but also as a fully coupled system with both natural and human components? What new rights and responsibilities flow from such a perception? As biophysical pressures mount, how can the environmental commons be shared so that destructive conflicts are avoided and human wellbeing enhanced?

These questions lead inevitably to a convergence between issues of the biophysical environment and of human wellbeing. The very concept of human wellbeing is seen by some as value-laden and therefore forbidden territory for the natural sciences, with their stress on objective reasoning. However, the most powerful forces in the contemporary human-Earth system are those arising from human actions and desires, founded in a search for individual and collective wellbeing. The central importance of the quest for wellbeing is not diminished by the fact that the goal is perceived in multiple ways by individuals and societies. Therefore, in any holistic study of an Earth system in which nature and humans are fully interactive, environmental and human wellbeing are fundamentally coupled. Planet Under Pressure reinforced the need for the human and natural sciences to enter this difficult terrain together.

**"solutions" to "problems" are neither context-free nor value-neutral.**

## Science as a participant in the search for solutions

The third turning point was that the science of the Earth system is evolving to be both an observer and describer of global change, and also a participant in the search for solutions to sustainability dilemmas. Planet Under Pressure was a meeting in the active voice. Contributing factors to this emphasis included the balances noted above – female and male, natural and human sciences, and perspectives from the South and the North.

The Conference Declaration[2] concluded that: *Interconnected issues require interconnected solutions … technological innovation alone will not be enough. We can transform our values, beliefs and aspirations towards sustainable prosperity.*

And further (slightly paraphrased): *Research plays a significant role in monitoring change, determining thresholds, developing new technologies and processes, and providing solutions. The global-change research community proposes a new contract between science and society, to encompass three elements: (1) integrated goals for global sustainability, based on scientific evidence; (2) a new approach to research that is more integrative, international and solutions-oriented; and (3) new mechanisms for interactive dialogue at multiple scales.*

In this spirit, the conference saw the public unveiling of efforts to reshape the international structures governing global Earth-system science research. A new initiative, Future Earth (Figure 1), will succeed the present Earth System Science Partnership (ESSP) (see page 4 of this issue).

## The world beyond science

These three turning points in the Earth-system science community have counterparts in wider societies. However, in every case, the central ideas in the wider world are deeply contested.

Many individuals and groups in both the North and the South share a sense of urgency about the challenges of global sustainability, and the difficulties of moving fast enough to avert interlinked crises. There are strong currents of awareness of the developing pressures on fronts such as climate change, water security, food security, biodiversity, nutrient cycling and other human-environment interactions. However, there are also strong counter-currents.

The standout contemporary example is scepticism about the idea that modern climate change is primarily anthropogenic in origin. Polarisation over climate change is particularly strong in the USA, the UK and Australia. Most evidently but not only in these countries, the climate battle also embroils the broader dialogue around environmental and human wellbeing, turning that dialogue into a contest as well.

One reason for this conflation is revealed by a question stated above: how can the environmental commons be shared successfully? The notion of sharing inevitably involves fairness and equity, both within and between societies and nations. Equity is seen by some as being in tension with other cherished values such as freedom and individual liberty. For these people and groups, sharing the environmental commons can become identified with an attack on liberty, leading them to a position in which climate mitigation and other efforts to share the commons must be opposed by any means[3].

Just as deeply contested in some communities is the idea that science, and Earth-system science in particular, should be a participant in the search for solutions. It suffices to say that "solutions" to "problems" are neither context-free nor value-neutral. In an interconnected world, almost any solution to a problem somewhere has ripple effects elsewhere, creating actual or perceived winners and losers. Participation in the search for solutions inevitably entrains issues of fairness, justice and equity, and the balance between these values and those of freedom and individual liberty.

## Reshaping the compact

Earth-system science is entering new and difficult territory. Funtowicz and Ravetz[4] described this terrain 20 years ago as "post-normal science": a mode of scientific enquiry that is appropriate when "facts are uncertain, values in dispute, stakes high and decisions urgent" – a tailor-made description of the issues central to Earth-system science. This mode of enquiry is one where "problems are set and solutions are evaluated by the criteria of broader communities [in addition to science and engineering]. … Post-normal science is indeed a type of science, and not merely politics or public participation"[4].

As with so much else, the concept of post-normal science is itself contested, to the extent that the phrase has become a term of abuse in the climate-sceptic community. The abuse is unwarranted. There is clearly a need to engage in forms of enquiry along the lines defined by Funtowicz and Ravetz, because the leading issues of our time are indeed characterised by uncertain factual knowledge, disputed values, high stakes and an urgent need for decisions. Science, with its commitment to reason and observational evidence, is a critical contributor to these issues, but science is not the only voice in the room, and workable solutions need to account for a plurality of voices.

As Earth-system science enters this new terrain, two points of reference remain critical. First, across the full spectrum of the natural and human sciences, Earth-system science is founded on principles of reason, logic and the primacy of observational evidence over dogma or ideology. The challenge of understanding the Earth system – its climate, water, land, soils, biota, ecosystems, societies, economies and cultures, and their interactions – demands the fullest commitment to these principles.

Second, Earth-system science speaks directly to human values and to policy. Some basic scientific conclusions about the Earth system are now starkly evident from a multitude of observations showing that the finitude of our planet is an imminent strong constraint on unfettered growth in material consumption. It is necessary to think about sharing finite resources, and therefore about equity, because the sharing needs to be fair and just if it is to work[5]. Such conclusions explicitly contradict broad policy directions, still dominant around the world, that are founded on assumptions of endless growth in material throughput. It is no longer possible for Earth-system science to remain "value-free" and detached from policy.

**Workable solutions need to account for a plurality of voices.**

These two reference points – commitment to reason and logic, and a willingness to engage with human values and policy – are at the heart of a reshaping of the compact between Earth-system science and society. It is still early, and much hard work remains to be done before both partners in the reshaped compact are comfortable with the relationship. ▮

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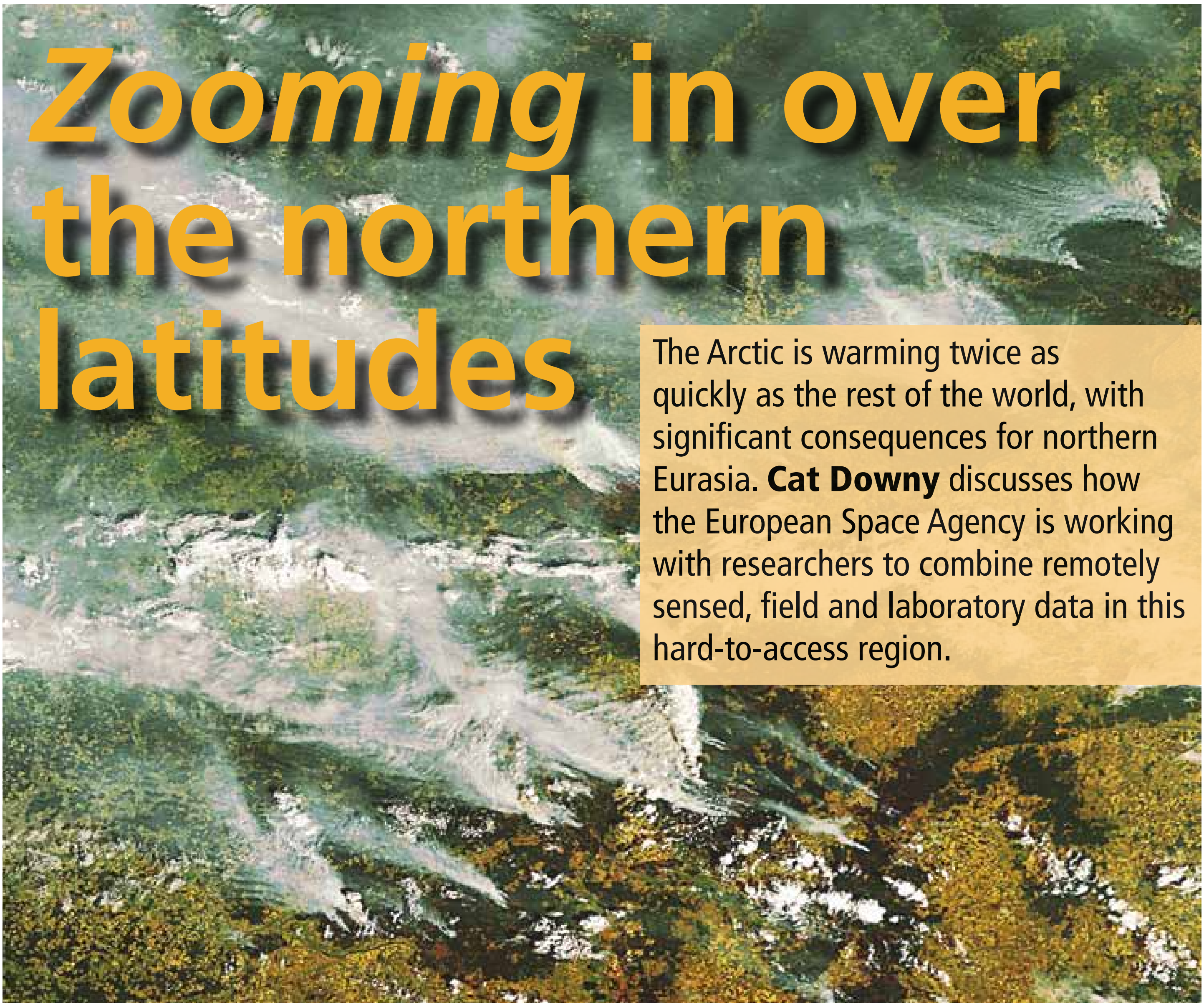
# Zooming in over the northern latitudes

The Arctic is warming twice as quickly as the rest of the world, with significant consequences for northern Eurasia. **Cat Downy** discusses how the European Space Agency is working with researchers to combine remotely sensed, field and laboratory data in this hard-to-access region.



European Space Agency/Envisat. Smoke over Moscow.

Warming-induced changes are progressing faster than predicted in some boreal regions, suggesting a potential non-linear response to climate change. Despite this, we know comparatively little about the response of the Eurasian boreal zone. Although a limited number of sites are well studied, the size and inaccessibility of the land area pose a challenge for monitoring, measuring and assessing how changes feed back into regional and global climate. This is not ideal given this vast region represents the largest terrestrial ecosystem on Earth and is estimated to store more carbon than the temperate and tropical forests combined.

**Thawing permafrost could release huge amounts of carbon.**

Satellites provide a wealth of observations on the land-atmosphere interface in northern Eurasia. We need to transform these into information that will help us understand the climate system. With this in mind, the European Space Agency (ESA) has set up several projects with scientists working in the tundra and boreal regions. These projects combine satellite observations with field and laboratory data in innovative ways to provide better services for monitoring and tracking environmental changes. Here I consider three examples of how this collaboration might increase our understanding.

## Monitoring permafrost

In a warming world, thawing permafrost could release huge amounts of carbon and methane to the atmosphere (see page 12 of this issue); monitoring changes to the permafrost is thus critical. The ESA Permafrost project brought together groups of scientists specialising in permafrost, in conjunction with the International Permafrost Association (IPA), to develop observations and tools to monitor permafrost. Existing satellite products of key indicators of permafrost change were harmonised, adapted and validated over three scales – local, regional and pan-Arctic – in response to a range of user requirements. The pan-Arctic products cover all permafrost-affected areas north of 55°N, while five regional service cases have been identified for higher resolution products.

A 'Permafrost Processing System' integrates the new satellite products with existing information on the state of permafrost. Where there is enough information, the system automatically processes new data to update features such as land-surface temperature, soil moisture, surface state (frozen/unfrozen), and lake distribution. This allows updates on some features to be sent out to the permafrost community on a weekly basis. The new datasets are available online along with tools to visualise the data, and also via the PANGAEA Open Access library (DUE Permafrost Project Consortium 2012). These products have also proven useful beyond the monitoring of permafrost; some have already been used to test regional models, such as land-surface models as well as global climate models. Others have applied the products to test tree ring series of $^{13}C$ and for coastal erosion and weathering studies.

## Methane emissions

Although the total quantity of methane emitted each year is fairly well understood on a global scale, the sources of methane and their spatial and temporal distribution are not well constrained. Boreal Eurasian lakes and wetlands are a significant source of natural methane emissions but remain poorly quantified. ESA's ALANIS (Atmosphere-LANd Interaction Study) Methane project uses satellite data to test the UK Met Office's land-surface model JULES. During the project, datasets of regional and local wetland-extent dynamics, snowmelt onset/duration/end, freeze onset and atmospheric methane concentrations were developed, extended and improved (Bartsch *et al.* 2012). These were then used in the first large-scale evaluation of the JULES wetland emission scheme, with the aim of improving its estimates of methane emissions. The datasets were able to successfully highlight areas for improvement – for example, the treatment of wetland hydrology and atmospheric chemistry – with a view to increasing our confidence in climate models. The importance of consistency when evaluating models was also made clear, both in terms of defining parameters and coverage in time and space, the latter being more important than having high-resolution data.

## Smoke-plume heights

Biomass burning events in boreal regions have consequences for carbon storage and can have a significant impact on the atmospheric chemistry from regional to global scales. Most fires deposit their emissions in the atmospheric boundary layer (below about two kilometres). However, in certain conditions and particularly at high latitudes, fire emissions can be injected into the upper troposphere or even higher, in the lower stratosphere (around 10km). Here the trace gases and aerosols have a much longer lifetime and therefore have a much longer lasting impact on the atmosphere, over a greater region.

The ALANIS Smoke Plume project is helping put together more reliable knowledge of plume injection heights, as well as a proper tracing of related fire emissions into the atmosphere. We can model these processes much better as a result of the new satellite products for fire-burned area, carbon monoxide (CO) emissions and plume injection height developed by the project (Muller *et al.* 2011). The integration of atmospheric CO into a land-atmosphere model, specifically designed to characterise fire-plume dispersal, confirmed that smoke plumes can be tracked reasonably well with satellite data. But it also highlighted a number of interesting discrepancies between estimates of fire emissions. For a few fire events the emission estimates were much higher than originally modelled; in these cases it was found that the extra emissions came from peat burning below ground. Peat burning is hard to account for using standard approaches to emission estimates but has important consequences for long-term carbon storage and therefore its representation in land-surface models needs improving if we are to understand future climate feedbacks.

Our understanding of climate change in the northern latitudes hinges on steady and continuous monitoring. ESA will continue to work with IGBP and other communities to ensure that this need is met. ▮

**Peat burning is hard to account for using standard approaches.**

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The projects described were funded under the ESA EO programmes Data User Element [Permafrost] and Support To Science Element [ALANIS Methane and ALANIS Smoke Plumes]. Further information on past, present and upcoming projects can be found on their websites: www.esa.int/due and www.esa.int/stse

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