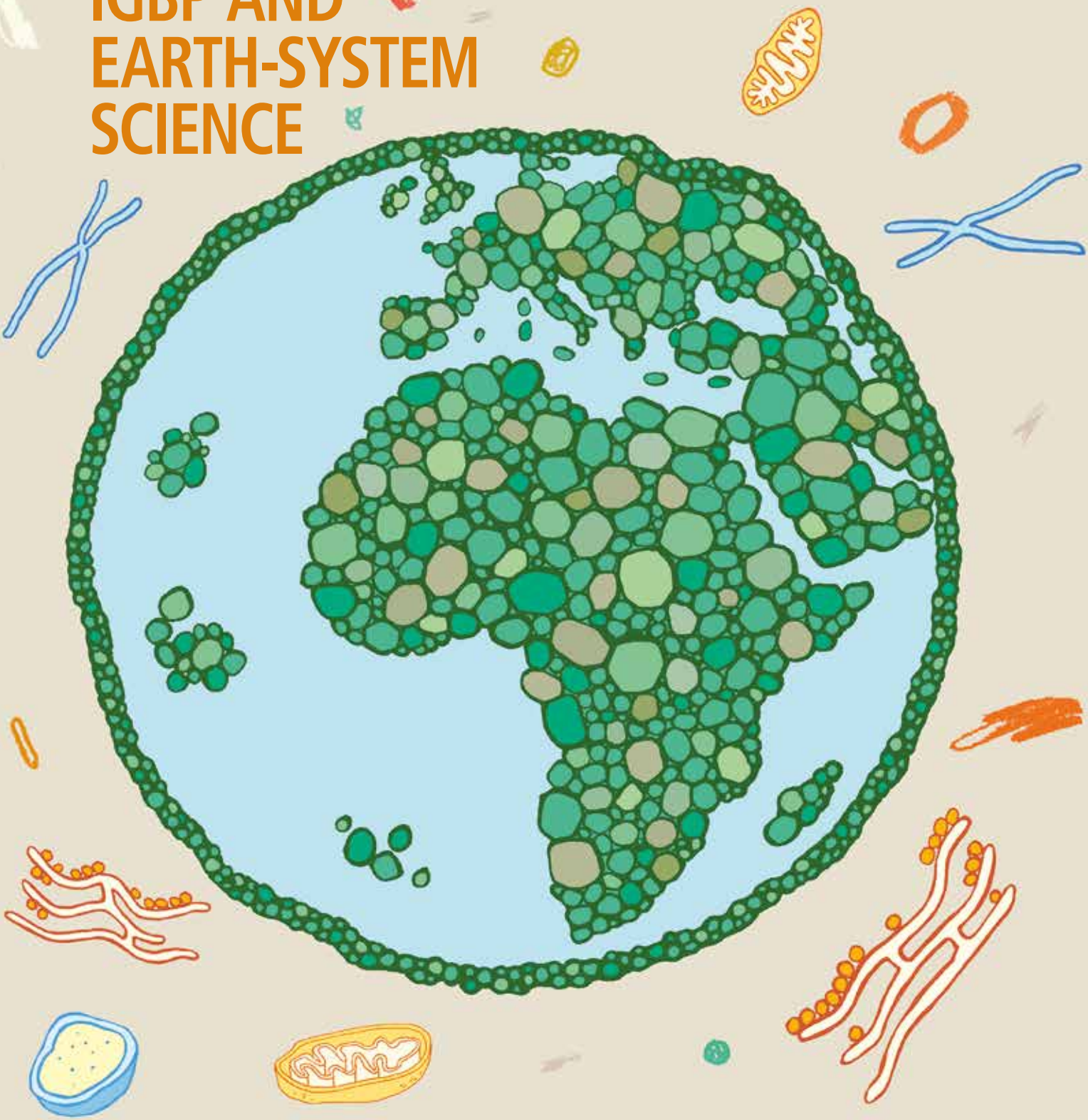
Global Change

International Geosphere-Biosphere Programme Issue 84 ▮ November 2015

IGBP AND EARTH-SYSTEM SCIENCE



GLOBAL CHANGE IGBP International Geosphere-Biosphere Programme

www.igbp.net

Earth-system science for a sustainable planet

ICSU International Council for Science

Contents

Cover image

The Earth system crystallised as an object of inquiry in the early 1980s. IGBP was set up to focus on the interactive physical, chemical and biological processes that regulate this system as well as the influence of human actions. Here the system is represented as a cell under a microscope. The elements surrounding the cell could be creatively interpreted as the various Earth-observation satellites that have been crucial to IGBP research over the decades.

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REGULARS

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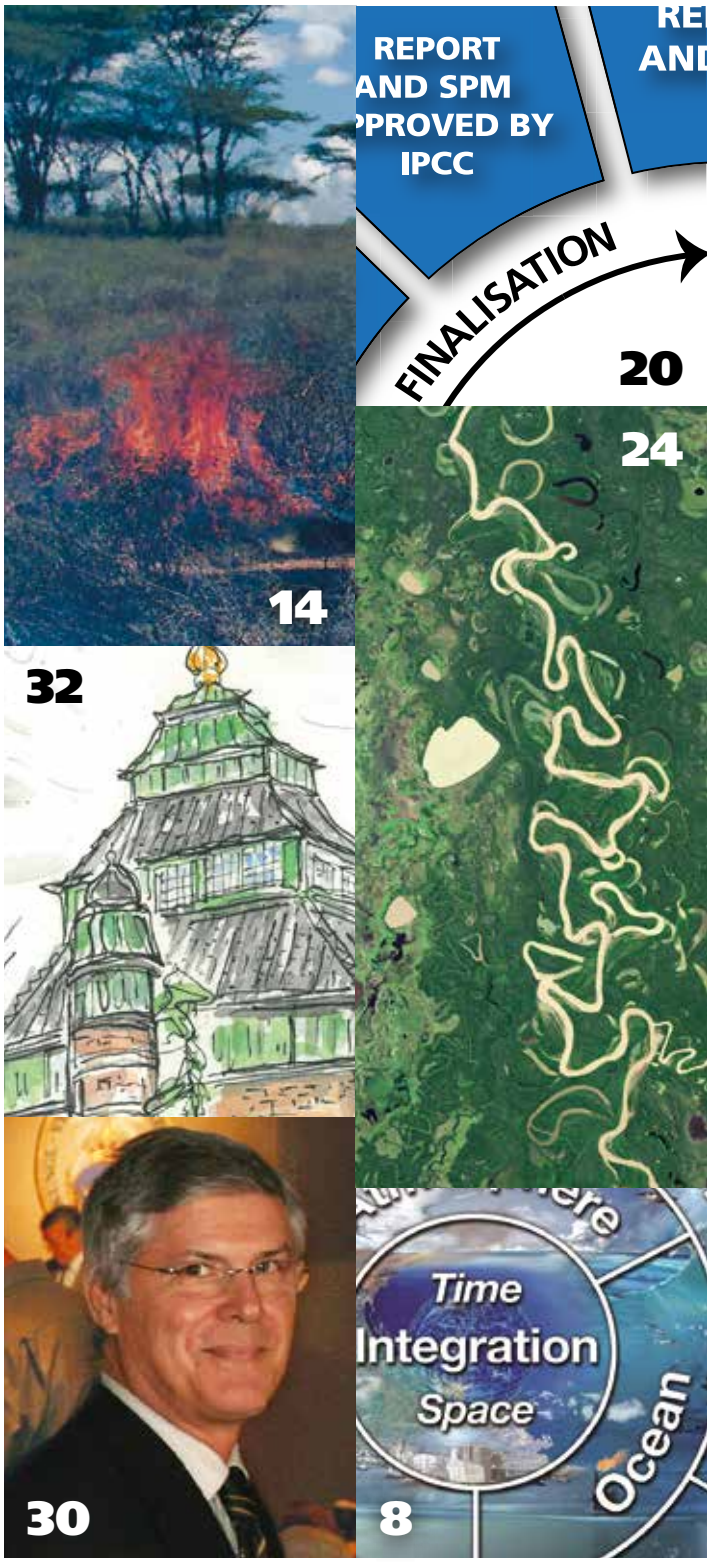
FEATURE



Global Change has primarily published research and opinion from within the extensive IGBP network.

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Editorial

Sybil Seitzinger and James Syvitski

Chair
James Syvitski

Former Executive Director
Sybil Seitzinger

IGBP emerged in the mid-1980s in response to the growing recognition that understanding the Earth system required an international, integrative effort. It was an ambitious undertaking that, by almost any measure, has turned out to be a resounding success. Suffice it to say that the advances in Earth-system science or the development of the Anthropocene concept would not have happened without IGBP.

But all good things must eventually come to an end: IGBP will close at the end of this year to make way for the Future Earth initiative. While the Secretariat in Stockholm and the global Scientific Committee will cease to exist, many of IGBP's core activities and international projects will continue under the sponsorship of other coordinating bodies, such as Future Earth.

The development of a highly collaborative global community of researchers interested in Earth-system science is one of IGBP's greatest achievements. Many in our community say that IGBP provided the information, tools and experiences that helped them to develop a global perspective – a worldview with cultural awareness and awareness of the diversity of the environmental changes under way.

We want to draw attention to the role our national committees played, particularly in the early development of IGBP. Although their number has fluctuated over the years, even in this final year of IGBP over 50 countries have IGBP or other global-change committees.

These national efforts built capacity by organising IGBP-oriented scientists within their own countries and helping to connect them with the broader international IGBP community (see page 14 of this issue). Many committees were also instrumental in informing local and national governments on the many nuanced aspects of global change.

NASA played a key role in laying the intellectual groundwork for IGBP, and many of our researchers worked very closely with NASA and other Earth-observation agencies such as the National Oceanic and Atmospheric Administration (NOAA) and the European Space Agency (ESA) (see page 24 of this issue). This collaboration was fundamental for much of IGBP's success and that of its projects.

Among IGBP's many contributions to policy, we are particularly proud of its scientific contributions to the Intergovernmental Panel on Climate Change (IPCC). As noted on page 20 of this issue, IGBP contributed to the IPCC since the very first assessment report: IGBP fed its research via its community's authorship and review of chapters, participation in workshops and panels, and the publication of papers and models that were key to the assessment.

Most of the heavy lifting has been done by IGBP's core projects. Each of them took on a domain of the Earth system, coordinated international research and, more recently, connected it to societal issues. Whereas our projects have mostly organised science while providing timely updates and early warning of newly discovered issues, they have also converted their science into useful products – for example, a land-use classification system and global databases of greenhouse gases, land-use change and historical sea-level rise – and summaries for policymakers on such topics as black carbon and ocean acidification.

The list of those who have contributed to IGBP's success would run into tens of pages. Here we must simply thank all members of our community (young and not so young) and the IGBP Secretariat through the years. We are also grateful to our funders; the International Council for Science (ICSU); decision-makers who have contributed to and used the work of IGBP; and the broader global-environmental-change scientific and policy communities.

We will celebrate IGBP's legacy and hand over the baton of global-change research to Future Earth at this year's American Geophysical Union meeting in San Francisco. We warmly welcome you to attend this event!

Editorial

Ninad Bondre

Senior Science Editor and Advisor Ninad Bondre

As IGBP draws to a close, fragments of the programme's past have managed to find their way to my desk. Among them is a slightly yellowing copy of the first issue of what used to be called the *Global Change Newsletter*. Published in May 1989, this issue marks the beginning of IGBP's diverse and highly successful communications efforts.

The *Global Change Newsletter* started out primarily as a source of information for the IGBP community and other interested scientists. It carried reports of various committee meetings and workshops around the world, as well as updates from the Secretariat and IGBP's national committees.

From about the mid-1990s, the newsletter began to carry an opinion piece by the Executive Director and, beginning in the late 1990s, several opinion pieces as well as articles addressing outstanding scientific questions. Perhaps the most famous and best cited of these is the article on the Anthropocene by Paul Crutzen and Eugene Stoermer, published in issue 41.

Going through the early newsletters, I found some gems that should delight not only scientists but historians of science, editors and communicators too. For example, I stumbled across a photograph of IGBP Scientific Committee members and Secretariat staff in front of the falling Berlin wall in 1989; a report from the USSR national committee; recollections of IGBP's setting up by Thomas Malone; and brief thoughts by Eric Barron on the relative merits and demerits of "rich tapestry" versus "flagship" models of IGBP and its core projects.

In 2009 – the year that former Director of Communications Owen Gaffney and I joined IGBP – the newsletter underwent a transformation, emerging in the form of the magazine you have been reading for the past several years. Owen and I both wanted to reach a much wider audience that included policymakers, business and industry, the media and the general public. We also wanted to introduce a more contemporary look and feel.

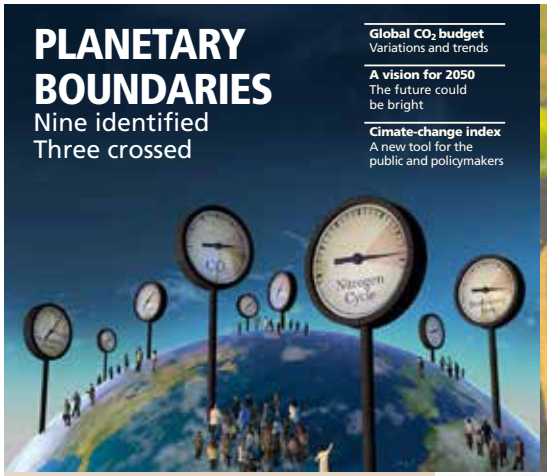
Owen thus oversaw a thorough redesign: he introduced a front-half including editorial and news sections, and a back-half containing commissioned and in-house articles. Although research emerging from IGBP's core projects continued to inform the content, we opened the magazine up to perspectives from other actors and on other topics.

Editing the magazine has been a great learning experience. My colleagues and I have received overwhelmingly positive feedback over the years. It's not fair to single out any one article, but for me the opportunity to interview Elinor Ostrom – soon after she was awarded the Nobel Prize in Economics and not long before she passed away – was certainly a high point.

As the editor of the final issue, here I can voice appreciation of the work of the editors, freelance copy-editors, communicators and designers involved in producing *Global Change* over the years. In alphabetical order these are: Anna Bastås, John Bellamy, Gunilla Björklund, Clare Bradshaw, Hilarie Cutler, Susannah Elliot, Owen Gaffney, Erik Huss, Naomi Lubick, Sheila Lunter, Suzanne Nash, Petra Nilsson, Angelina Sanderson, Wendy Smith, Mary Ann Williams and Bill Young. Suzanne Nash owes special mention for helping IGBP out from time to time even after her retirement.

I acknowledge the Secretariat staff who helped out in all sorts of ways including mailing and distribution, and beyond. On behalf of IGBP I also thank its regional office in Brazil, which has mailed out copies of the magazine to developing countries around the world for many years. Finally, the newsletter/magazine would not have been what it is without the time and energy of its many contributors. Certainly the articles I edited underwent numerous revisions, and I am grateful to all the authors who worked with me for their contributions and patience.

Future Earth, the initiative that will replace IGBP, is focusing on various modern communication tools including blogs and social media. So it should. Yet I am always reminded that many readers of the magazine appreciated having something to hold and flip through. I hope that Future Earth will consider including a magazine in its portfolio of products. If so, the *Global Change* magazine will serve as an excellent template.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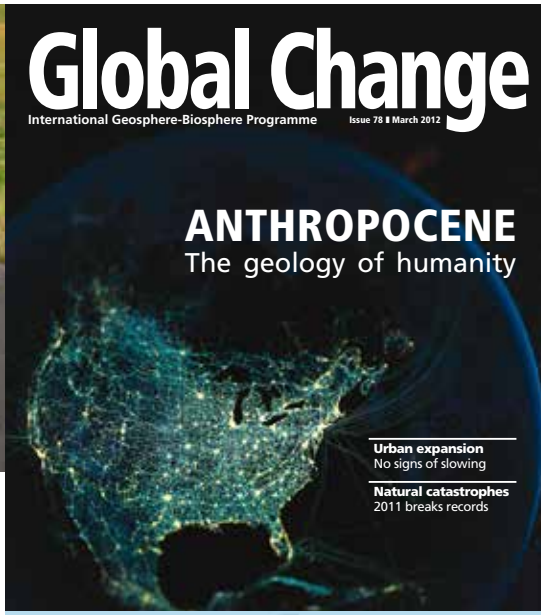
LAND GRABS AHEAD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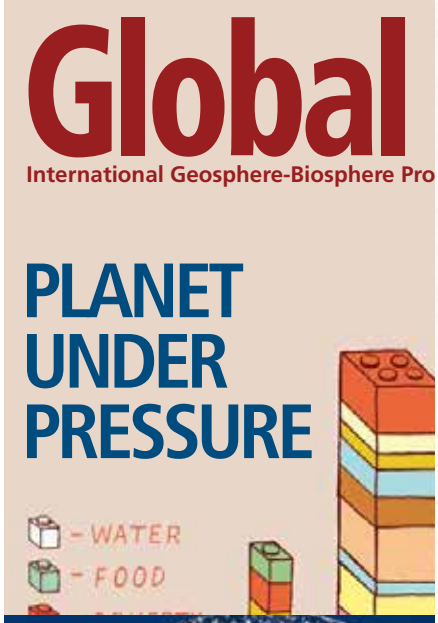
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GLOBAL CHANGE
NEWS LETTER
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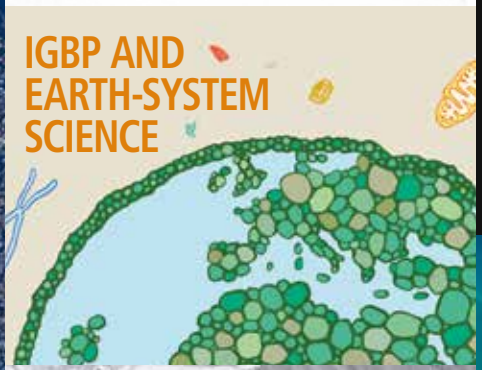
EMISSIONS SCENARIOS
Exploring pathways


REGIONAL TEMPERATURE RECONSTRUCTIONS
Landmark 2000-year analysis published


IGBP AND EARTH-SYSTEM SCIENCE


TIMBER!
Fall of Rome etched in rings?


THE CARBON ISSUE


METHANE UP NORTH
Vigilance, not panic


Change
rogramme
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Dynamic Deltas

IGBP hands over baton to Future Earth

IGBP will complete its mandate at the end of this year. The new initiative, Future Earth, is under way and poised to sponsor many of IGBP's projects and activities.

Its five secretariat hubs – one each in Montreal, Boulder, Paris, Tokyo and Stockholm – have been recruiting staff throughout the past year. Paul Shrivastava, formerly Professor of Sustainable Enterprise at Concordia University (Canada), is the Executive Director of Future Earth, based in Montreal. He was joined early in the Future Earth process by the Global Hub Director Fumiko Kasuga, a public health researcher, in Tokyo. Thorsten Kiefer, former Director of the Past Global Changes (PAGES) project, heads the Paris hub, while Anne Hélène Prieur-Richard, former Acting Director of DIVERSITAS, is heading the Montreal hub. Josh Tewksbury, an ecologist and conservation biologist formerly at the University of Washington, was appointed the first Colorado hub director in September. The Stockholm global hub continued its search for a director at press time.

Many of IGBP's core projects have migrated or are in transition to Future Earth, and new activities are in the works. For example, the China National Committee has initiated an expert committee on disaster early warning in the context of global environmental change. Future Earth also recently put out a call for proposals to establish regional offices in Africa.

In preparation for its closure, the IGBP Secretariat in Stockholm archived important documents pertaining to its institutional and scientific history as well as finances. Hard copies are to be stored at the Royal Swedish Academy of Sciences. An electronic archive will be housed at the Paris headquarters of the International Council for Science (ICSU), which sponsors IGBP. The IGBP website will remain online until 2026.

Kung. Vetenskapsakademien

The Royal Swedish Academy of Sciences

THANK YOU

MANY individuals and organisations have contributed to IGBP's success over the years. While it is impossible to thank them all individually here, we owe each of them a huge debt of gratitude. We acknowledge the tremendous efforts of the thousands of scientists who devoted their time to IGBP on a voluntary basis since its inception. IGBP would not have been the organisation it is without the work of past and present Secretariat staff. Particular thanks go to Charlotte Wilson, who has held together the office and staff with her dedication and diligence since she joined in 1999. Thanks also to all of the current and past staff of the Secretariat. We would also like to thank the Royal Swedish Academy of Sciences for hosting the programme for almost three decades.

– Karen Smyth, Acting Executive Director, IGBP

Synthesis update

IN 2012 IGBP decided to launch an overarching synthesis focusing on the Anthropocene, Earth-system science and core-project accomplishments. Papers emerging from these three topics are currently undergoing peer review and should be published in the coming six months.

The seeds for the Anthropocene synthesis were sown at a workshop last year in Washington, DC. The workshop, which was co-sponsored by the International Human Dimensions Programme on Global Environmental Change, brought together natural and social scientists to explore the concept's many dimensions. The workshop led to the development of a suite of papers on topics including conceptualisation; modelling and methodological challenges; data needs; Anthropocene futures; and governance. The papers are being reviewed for eventual publication in the journal *Global Environmental Change*. Some of this work will inform a union session on the Anthropocene at the American Geophysical Union (AGU) fall meeting in December.

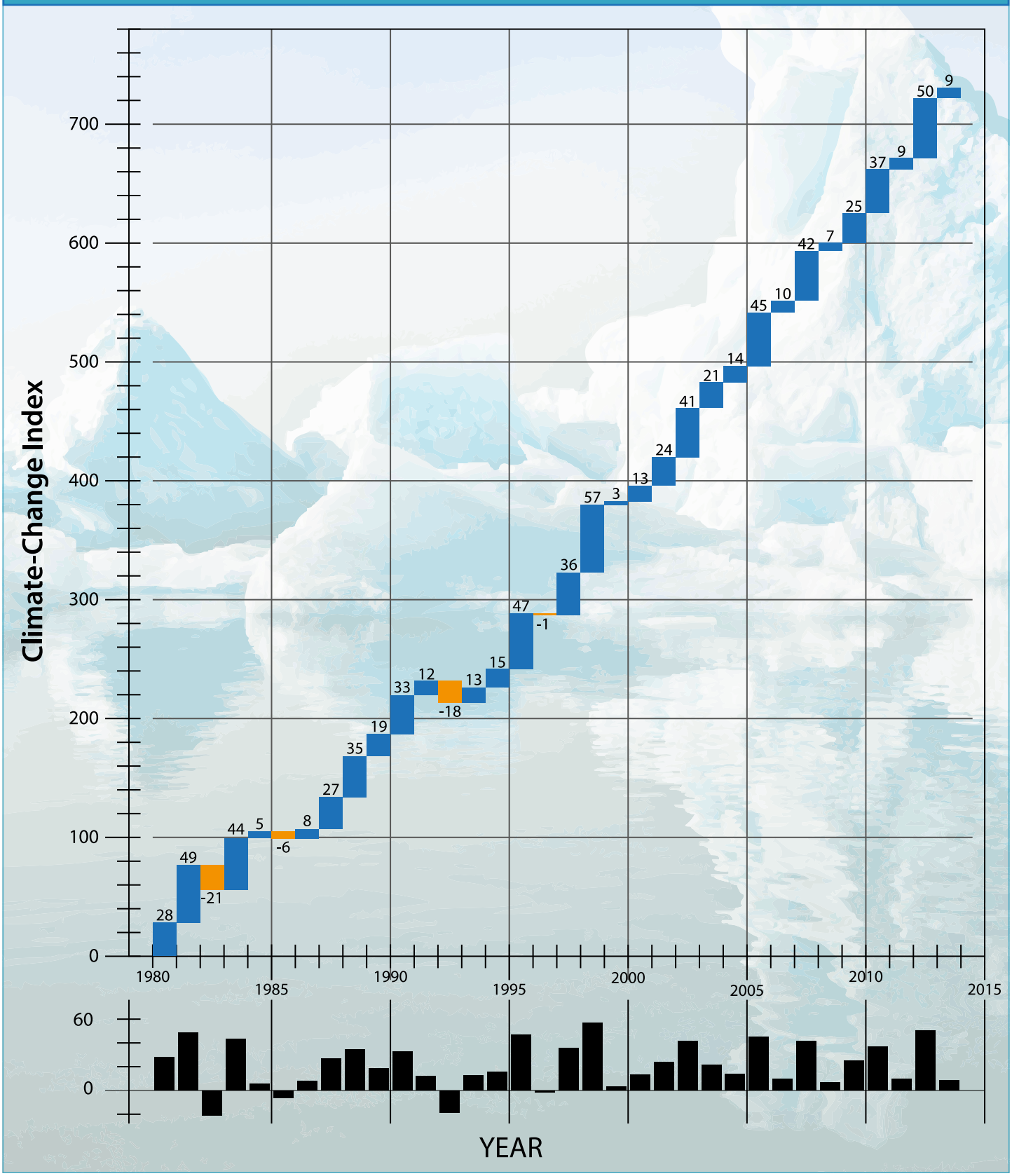
Papers on IGBP's contributions to Earth-system science and the accomplishments of its core projects are undergoing review for eventual publication in the journal *Anthropocene*.

BELLA GAIA

IGBP landmark synthesis event at AGU

THE fall meeting of the American Geophysical Union (AGU), which takes place in San Francisco every December, is one of the largest annual gatherings of geoscientists. This year's meeting will witness a special package of activities to celebrate IGBP's legacy in the form of a landmark synthesis event. IGBP is co-sponsoring tens of scientific sessions that will showcase its final synthesis and the work of its core projects. The Secretariat has put special emphasis on raising funds to facilitate the attendance of more than 20 researchers from the developing world. Some of these researchers will participate in a two-day workshop on co-design and co-production of knowledge to be held at Stanford University in advance of the AGU meeting. Other events include an evening reception for the wider IGBP community and a music and dance performance by the group Bella Gaia.

The Climate-Change Index brings together four Earth-system parameters: sea level; global average land-surface temperature; atmospheric carbon dioxide; and Arctic sea-ice minimum. The index gives equal weight to each parameter, thus not emphasising one component more than another. As with previous years, the 2013 index shows an unequivocal rising trend. For more information about the methodology and the Climate-Change Index, see issue 74 of *Global Change* or go to the IGBP website (www.igbp.net/globalchange/climatechangeindex.html).



Peter Liss | Kevin Noone | Sybil Seitzinger | Thomas Rosswall | Chris Rapley | Will Steffen | James Syvitski

REFLECTIONS ON EARTH-SYSTEM SCIENCE

The development of Earth-system science has been inseparable in many ways from IGBP's scientific and institutional evolution. We asked IGBP's past and present leaders to reflect on the programme's contributions to this discipline and the way ahead.

During the 1980s, based on decades of disciplinary research, scientists and policymakers grew to realise that the Earth was in fact an integrated system. As a seminal NASA report from 1986 put it, "This insight has set the stage for a more complete and unified approach to its study, Earth System Science". The time was ripe for an international programme that would unify not only disciplines but also the global community of scientists to understand the Earth as a whole. This programme, IGBP, will close at the end of 2015 after three decades of coordinating and facilitating research on global change. In this context, we posed a series of questions to IGBP's past and present chairs and executive directors about the programme's contributions to Earth-system science and the future of this discipline. Below we present their edited responses:
Thomas Rosswall (Director, 1987–1994);
Peter Liss (Chair, 1993–1997);
Chris Rapley (Director, 1994–1997);
Will Steffen (Director, 1998–2004);
Kevin Noone (Director, 2004–2008);
Sybil Seitzinger (Director, 2008–2015);
James Syvitski (Chair, 2012–2015).

Q: How do you conceptualise Earth as a system?

ROSSWALL: IGBP was established around the time of the Gaia hypothesis and Jim Lovelock's attempts to view the Earth as a self-regulating system. IGBP's initial thinking was very much guided by the Bretherton diagram (see page 10), where the sun and humans were external factors and the World Climate Research Programme (WCRP) plus IGBP constituted the research needed to understand the Earth system. With the 2001 Amsterdam declaration and the establishment of the Earth System Science Partnership (ESSP), the human component became an integral part of the Earth system. At least that was the vision, even if reality did not move very quickly.

LISS: I sometimes liken the Earth as a system, and how our ideas about it have evolved, to a grand building. The bricks are equivalent to single disciplines, which then become linked together into pillars of the edifice – for example, biogeochemistry in IGBP and physics and maths in WCRP. Then the pillars are linked and roofed to complete the building, which I liken to Earth-system science. There's a limited amount of social science, as represented by the International Human Dimensions Programme on Global Environmental Change (IHDP), but it is not until Future Earth appears that the social sciences start to play their full and vital role.

RAPLEY: As the most complex object (that we know of) in the universe. The well-known Bretherton diagram from the 1980s gives you an idea: this diagram shows key interactions and feedbacks within the Earth system that bear on climate. When I was IGBP Director I added colour-coded domains to illustrate the relationship between WCRP, IGBP and IHDP. You will notice that human activities are condensed into a single element. There was in fact a social process diagram developed in the early 1990s that sought to expand on this.

STEFFEN: We put a lot of thought into just this question while working on IGBP's first synthesis from 1999 to 2002. The definition we came up with for the synthesis volume (see Chapter 1 by Frank Oldfield and myself) is still a very good definition: "In the context of global change, the Earth System has come to mean the interacting physical, chemical and biological global-scale cycles (often called biogeochemical cycles) and energy fluxes which provide the conditions necessary for life on the planet".

Then we went on to list a number of important features of the Earth system, including that "human beings, their societies and their activities are an integral component of the Earth System, and are not an outside force perturbing an otherwise natural system".

NOONE: My own concept of the Earth system is very nicely captured in the illustration we commissioned for IGBP from the artist Glynn Gorick when I was working at the Secretariat. [See page 11.] The Earth in its entirety is at the centre of my conceptualisation. It is whole; the Earth system itself does not distinguish between any of the "spheres" around which we tend to organise ourselves – the atmosphere, oceans, land, biosphere or geosphere. There is no dichotomy between humans and nature. Life is the heart of the Earth system and, while the system is amazingly resilient, change is a constant. Above all, the Earth system is something of majestic beauty.

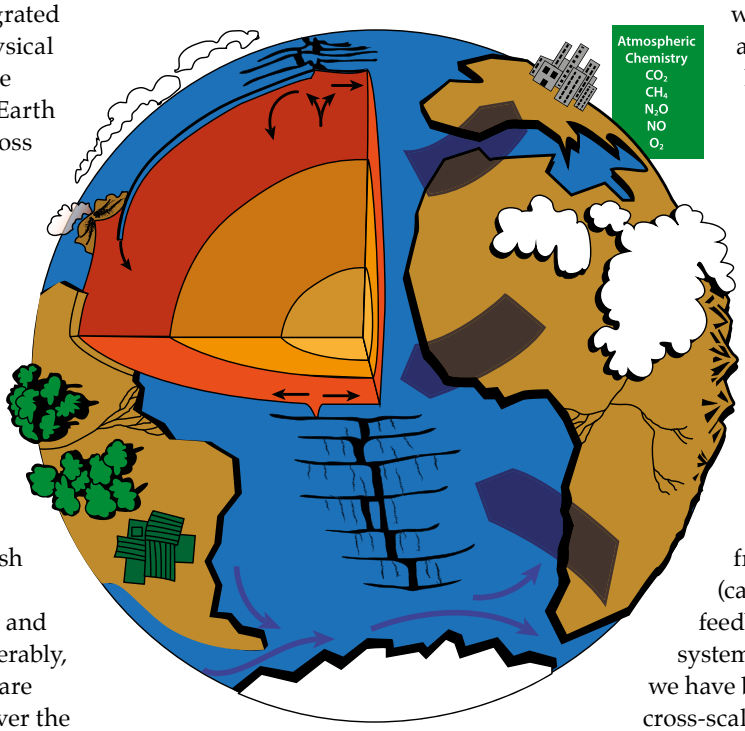
SEITZINGER: I conceptualise the Earth system through the lens of the Anthropocene: a complex, integrated socio-eco-bio-geo-chemical-physical system in which humans are the dominant force of change. The Earth system operates within and across all temporal and spatial scales.

SYVITSKI: This is an interesting question that begs to know the question's audience and its interest. At any given moment, the Earth system includes all the interconnections and teleconnections between the Earth's interior, the biosphere, cryosphere, hydrosphere and atmosphere, and oceans that slosh around at the Earth's surface.

In the world of IGBP the time and space of interest narrow considerably, as the focus is on how humans are impacting the Earth's surface over the past few thousand years – that is, the time it takes for ocean surface water to sink and deeper water to well up – and even just the past few hundred years when human population rose from a few hundred million to over seven billion. This historical period of human industrialisation is less than 0.0001% of the Earth's history. IGBP captures the Earth as a system by coordinating international projects that cover the appropriate Earth-system domains – the atmosphere, our continents and oceans, and the interactions between these domains.

Q: How has Earth-system science evolved during the past three decades?

ROSSWALL: Interdisciplinary collaboration has changed fundamentally during the past several decades. For example, during the International Biological Programme (1969-1974) it was very difficult to get communication going among the zoologists, botanists, hydrologists and others in order to shape ecosystem science. IGBP's early years were marked by difficulty in getting academics involved in studying biogeochemical cycles to talk to each other in the same language. Cooperation with WCRP wasn't easy at the time either, even on topics such as water that one would have thought were integrative. But IGBP was persistent and the horizon expanded slowly.



An early conceptualisation of the Earth system included the deeper Earth, but this fell out of favour later. Redrawn from *Earth System Science Overview*, NASA.

The ESSP took us further along this path by bringing together the four global-change programmes and diverse natural- and social-science disciplines. Future Earth, the latest initiative to emerge from the global-change community, represents a step change. Its approach of transdisciplinarity and co-design opens up an exciting new possibility to engage stakeholders in formulating problems as well as developing solutions.

RAPLEY: There has been a slow, painful and only partly successful move towards coordinating the research projects both within and between the major global-change programmes, as well as the projects carried out by other major groups. This is also the case with integrating and synthesising the results to understand the working of planet Earth as a system and provide insights and information of value to society. The problems are manifold but relate mainly to limitations of the academic rewards system, scientific training and cultural norms. At least now the global-change programmes talk to each other and treat each other with a degree of respect, which was not the case in the late 1980s and early 1990s. However, the ESSP was a disappointment, and I have grave doubts about Future Earth!

STEFFEN: It is really hard to describe the enormous progress in Earth-system science over the past three decades comprehensively but briefly. Here I'd like to highlight three strands of development that I think are important.

1) The past three decades have seen a remarkable shift from disciplinary thinking (cause-effect) to systems thinking – feedbacks, thresholds, abrupt shifts, system-level phenomena. I also think we have become wiser in dealing with cross-scale interactions, and particularly in a more cautious approach to scaling up from local to global levels.

2) Two or three decades ago it wasn't clear whether the social sciences would learn to think globally. The dilemma, as emerged from my discussion with IHDP's Larry Kohler, was whether existing high-profile social scientists could adapt to thinking globally or whether a new generation of social scientists needed to be developed in a bottom-up fashion. Looking back on this challenge, I think it has been ably met by the social sciences with a bit of both approaches. In my view, one of the spectacular successes has been

the rapid development of the field of Earth-system governance. I suspect the field of urban studies, in all its complexity, is also entering a rapid development phase. These two fields will likely be pillars in the Future Earth portfolio of activities.

3) The humanities have much to offer to Earth-system science. The best example of the potential of the humanities, in my view, is the Integrated History and Future of People on Earth (IHOPE) project. It takes a truly integrated view of the past (leading into the future) and asks some really fundamental questions. For example, why are some societies more resilient to external shocks and others less so? Research like this is not often considered to be Earth-system science, yet it should be front and centre in terms of informing the future evolution of the Earth system.

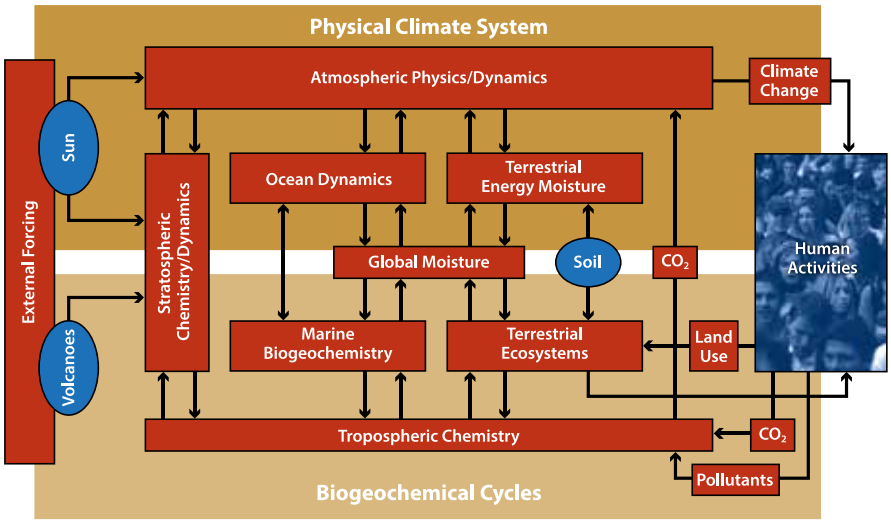
NOONE: I don't really think there was an "Earth-system science" about 30 years ago when I published my first paper. Even today, I'm not sure that we have a common definition of what Earth-system science is.

That is not to say that there has been no evolution in this area – quite the contrary. Earth-system science has gone from being an oddball notion to becoming recognised as a paradigm necessary for us to make progress on the "wicked" problems society faces today. We still haven't managed to properly integrate natural and social sciences in conceptualising the Earth system, though I do believe we have made significant progress. We are definitely behind the eight ball, though, in terms of figuring out how truly transdisciplinary research can be conceived and implemented. We need a proper infrastructure and reward system to support and encourage folks to work in this manner.

SEITZINGER: Within IGBP, Earth-system science has evolved from the development of some of the first global databases to studies primarily of individual components of the Earth system to more integrated Earth-system analysis. Throughout the past three decades there has been a steadily increasing focus on explicitly incorporating the human dimensions.

SYVITSKI: Three decades ago we could have drawn a cartoon or flow-chart of how the Earth operates as a system. And three decades ago we were making measurements on most aspects of the Earth system. But this science with a global reference was qualitative and primitive. Our observations (on the ground as well as from space) and data were far more limited. Our understanding of the carbon and nutrient cycles was so limited that we could not put together basic global budgets.

Most importantly, we had no computer model that could be used to test hypotheses. In the early 1980s we operated energy-climate models. A decade later we were coupling models that also contained climate, the ocean carbon cycle and atmospheric chemistry. Now our integrated assessment models also include sulphur and non-sulphur aerosol dynamics, the terrestrial carbon cycle, agriculture and other forms of land use, energy technology and significant upgrades to the other model components. Today, the models allow for predicting the influence of atmospheric greenhouse gases on a whole host of variables and can include such regional phenomena as changes in land-use practice.



The iconic Bretherton diagram. Redrawn from *Earth System Science Overview*, NASA.

Q: How has IGBP influenced this evolution in Earth-system science?

ROSSWALL: Had it not been for IGBP, the biogeochemical understanding of the Earth system would have been poorer. Also, the books IGBP published in relation to its first synthesis were, and are, seminal publications. The concept of the Anthropocene was very much stimulated by IGBP research, and the Planetary Boundaries also take a lot of IGBP research as a point of departure.

IGBP could have been considerably more important if we had engaged more strategically in essential policy processes, worked better with the private sector (e.g., through the World Business Council) and engaged with important NGOs. This has been done, but at least in the beginning it was not seen as a high priority. When I chaired a review of climate/global change in Norway in 2012, very few considered IGBP important despite so many Norwegians playing important roles in the programme's work.

STEFFEN: IGBP's implementation phase began in 1990 under the energetic directorship of Thomas Rosswall with the original six core projects, and further developed from the mid-1990s with Chris Rapley at the helm. It was a very productive decade, propelled by all of the energy of a visionary new international programme and further solidified by the development of a long-term institutional framework.

I was Executive Director of IGBP from March 1998 through June 2004: in my view this was a remarkable period for the programme in terms of the transition from its first to the second phase, the implementation of the first IGBP synthesis project, the landmark Amsterdam conference in 2001 and the prominent emergence of Earth-system science as a major feature of international global-change research. It was during this period that the ESSP emerged in response to the need for more integrated research. In many ways, the

ESSP, at least in its conceptual origins and its intent, was a forerunner of Future Earth.

NOONE: I can't think of an organisation that has been more influential in the evolution of Earth-system science than IGBP. Obviously I'm biased in this regard, but trying to be as dispassionate as I can, I still come to the conclusion that IGBP has been hugely influential.

IGBP started off as a collection of relatively independent projects that were broader in scope than many contemporary scientific endeavours, but each of which still had a rather disciplinary character. Over the years IGBP itself evolved to incorporate the notion that borders didn't belong in the Earth system, and moved to change its organisation to reflect this concept. This new conception is nicely depicted in the "onion diagram" that was published in *Eos* and in the IGBP Science Plan and Implementation Strategy. That is the organisation – IGBP Phase II – that I stepped into when I started at IGBP in 2004. I still use the onion diagram to illustrate one effective way in which Earth-system science can be organised.

SEITZINGER: H T Odum [an influential ecologist at the University of North Carolina at Chapel Hill] said that scientists should always look at their research from a one- to two-order larger scale – for example, if you're studying a lake, look at it also in the context of the entire region. This is one way that IGBP has influenced the work of individual scientists on the Earth system.

Moreover, it provided the framework and support for "social physics" to inspire new ideas in Earth-system science. This was achieved by bringing people together to collaborate across disciplinary and geographic boundaries, moving people out of their comfort zones and into direct participation in conferences and workshops. Also, very importantly, through deeper engagement in planning and co-authoring syntheses and commentaries.

SYVITSKI: Without IGBP and its core projects, there would not be Earth-system science as we know it today. IPCC would not be the same – just imagine no biogeochemistry in our understanding of the land-ocean system – nor would modern climate change be put into a historical perspective. The modern level of coordination on Earth observations beyond the space agencies would probably not exist. International science would have remained patchy, with many countries lagging behind in their contribution. The US and Europe would have dominated the world of science in unhealthy ways.

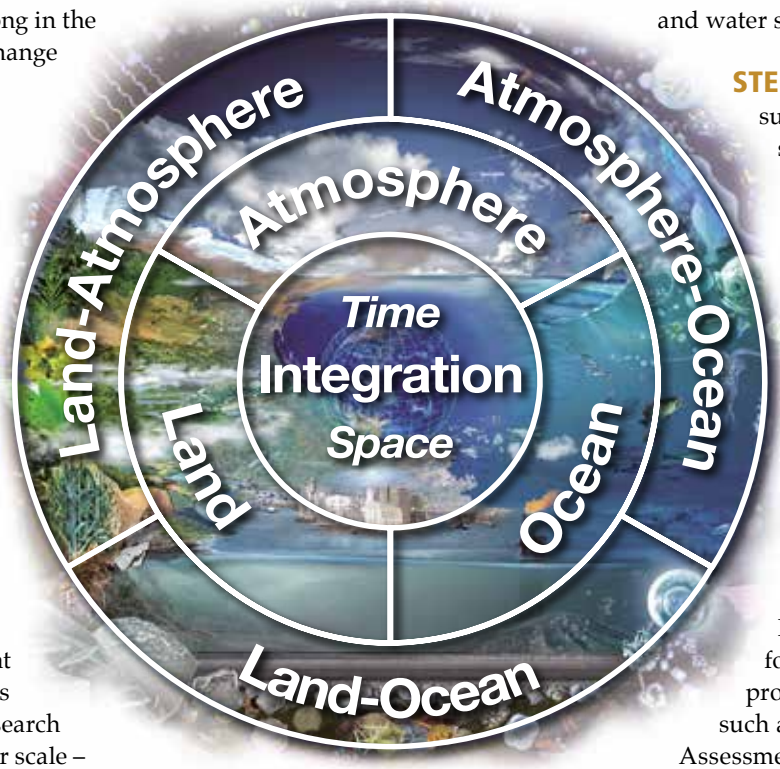


Illustration by Glynn Gorick underlying the "onion diagram".

Q: How successful has IGBP been in focusing scientific, policy and public interest on global change, not simply climate change?

ROSSWALL: Apart from the interaction of biogeochemistry with the climate system, IGBP has been successful in also looking at issues such as ocean acidification, transboundary air pollution, and so forth. Some of IGBP's syntheses have been assessments, although they might not be recognised as such, unlike the IPCC.

LISS: Because of IGBP's breadth it has embraced the science necessary for many policy aspects in addition to climate change. For example, air pollution (International Global Atmospheric Chemistry, IGAC), land degradation (Global Land Project, GLP) and biodiversity (Global Change and Terrestrial Ecosystems, GCTE, and eventually leading to the independent DIVERSITAS programme).

RAPLEY: My impression is that IGBP has been especially successful at highlighting in informative and useful ways the broader issues of land-use change, food and water security, and so on.

STEFFEN: Only partly successful, I think. There is still a huge emphasis on climate change, and this is perhaps appropriate given that it represents a rapid destabilisation of the energy balance at the Earth's surface. But I think that this situation is starting to change, especially over the past decade. This shift can trace some of its origins to a set of IGBP core projects (GCTE and Biosphere Aspects of the Hydrological Cycle, BAHC, for example), as well as other programmes and initiatives such as the Millennium Ecosystem Assessment and DIVERSITAS.

The legacy of all of these efforts can be seen, for example, in the Planetary Boundaries framework, in which climate change is one of nine boundaries.

IGBP's superb communication team played a significant role in getting global change – not just climate change – recognised beyond the research community.

NOONE: I think IGBP has been fairly successful in focusing scientific attention and interest on issues of global change. There have also been successes in the policy and public arenas too, but I personally feel that credit for many of these is more appropriately due

to individuals associated with IGBP rather than the organisation itself. IGBP provided the support structure and soapbox (which was invaluable), but ultimately delivering the messages was effected by some of the talented folks associated with the organisation.

In my time at IGBP, we were going through a bit of an identity challenge (not a crisis!). The prevailing opinion was that IGBP was a science organisation that should be policy relevant but not policy prescriptive. We were moving into the domain of actively promoting new science results to wider audiences and actively seeking contacts in the policy and to some extent the private sectors.

Still, we were very much in a broadcasting mode, not really an interactive one. Nobody in the organisation wanted it to become another Greenpeace or WWF, but there was a realisation that we needed to be able to play some additional roles than the traditional one of dispassionate scientist disconnected from society. We had broken down the borders between scientific disciplines in the organisation, but still had ones between us and the rest of society.

SEITZINGER: One of the strengths of IGBP is that it does not only focus on climate change, but on the broader issues of global change. I made a back-of-the-envelope analysis of activities across IGBP and estimated that about half of our activities are primarily focused on climate change and the other half on other global changes.

From a policy perspective IGBP has always contributed to the IPCC, which has influenced policy (although IPCC has had less influence than we would have liked). In the past decade IGBP has developed many policy briefs and engaged directly with international conventions [see page 20]. IGBP has probably had the least impact on public interest in global change, although many of our communication products – visualisations, press releases, the *Global Change* magazine, etc. – have reached a broad audience.

SYVITSKI: One of the concepts developed by IGBP is the notion of the Anthropocene, in which humans were collectively creating a new geological epoch wherein atmosphere, ocean and land biogeochemical cycles were under the strong influence of humans and their societies. The extent and rate at which humans have modified Earth's land surface, through deforestation, mining, urbanisation and agricultural practice, is striking. Humans are now the largest force in the movement of sediment – greater than ice, wind and water.

IGBP has led efforts on understanding the impact in the growth of megacities, how deltas are sinking faster due to subsidence than sea level is rising, and how oxygen-depleted dead zones in our coastal oceans are tied to upstream agricultural practices. IGBP has reached out to involve social scientists at every level of its organisation and has help set the agenda for Future Earth with regard to environmental sustainability. The IGBP agenda as of 2014 contained about 70% Earth-system science and about 30% human dimensions science.

Q: Where does Earth-system science go from here in view of the changing landscape of science-society-policy interactions?

ROSSWALL: Well, it seems that Future Earth is the way forward. But maybe the time has come to change the way scientific collaboration is planned and executed. During the Norwegian review I mentioned earlier, almost all scientists knew about the International Polar Year (IPY). The reasons include dedicated funding and firm and published criteria for deciding on affiliated projects. This was a win-win-win for scientists, funders and sponsors.

But the way Belmont funding is developing, I see no signs of it working in support of a strong Future Earth programme. In the future the most crucial factor is how to reach out to the new generation of potential Earth-system scientists with a very compelling story. Also, it is essential to clarify how they can get involved. They have a competitive future and to attend planning meetings is probably not the most important activity to prepare them for a successful career. Especially if the IPY model of dedicated funding is absent.

LISS: What do you expect me to say, except Future Earth! We are in the first stages of completing the building of the Earth-system science edifice, with the needs of society framing the questions to be addressed.

RAPLEY: A single overarching programme is the correct approach in principle. It would contribute to both scientific understanding of the Earth system (including its future trajectory) as well as provide information of value to society – as determined by appropriate representatives of society in an adaptive and co-productive manner.

The problem is that if the estimates of remaining permissible carbon emissions are correct, there is no time for a leisurely 10- to 20-year science programme. Action is required now and this requires the global-change science community to prioritise communicating and delivering what it knows already to society in a manner that galvanises and facilitates necessary action. I don't see that recognition with Future Earth.

STEFFEN: Actually, the "changing landscape of science-society-policy interactions" is part of the Earth system itself, in fact, a very important part. As we look forward towards the trajectory of the Earth system, the trajectory that the human enterprise takes will be critical. And an important part of any scenario of the human enterprise is how societies will react to the ongoing developments in science and how this knowledge-generation process intersects with the policy and governance communities. Climate change is a classic example of this. So Earth-system science would be wise to include the changing landscape of science-society-policy interactions in any of its future scenarios, and it actually does so in some of the excellent research over the past few years in the field of Earth-system governance.

NOONE: I think the University College London report that Chris Rapley and others recently published (*Time for Change? Climate Science Reconsidered*, 2014) contains a lot of good ideas and analysis in this regard. The relevance and utility of Earth-system science will be substantially augmented if we are able to

successfully develop and play roles that go beyond the linear science model of merely communicating scientific facts.

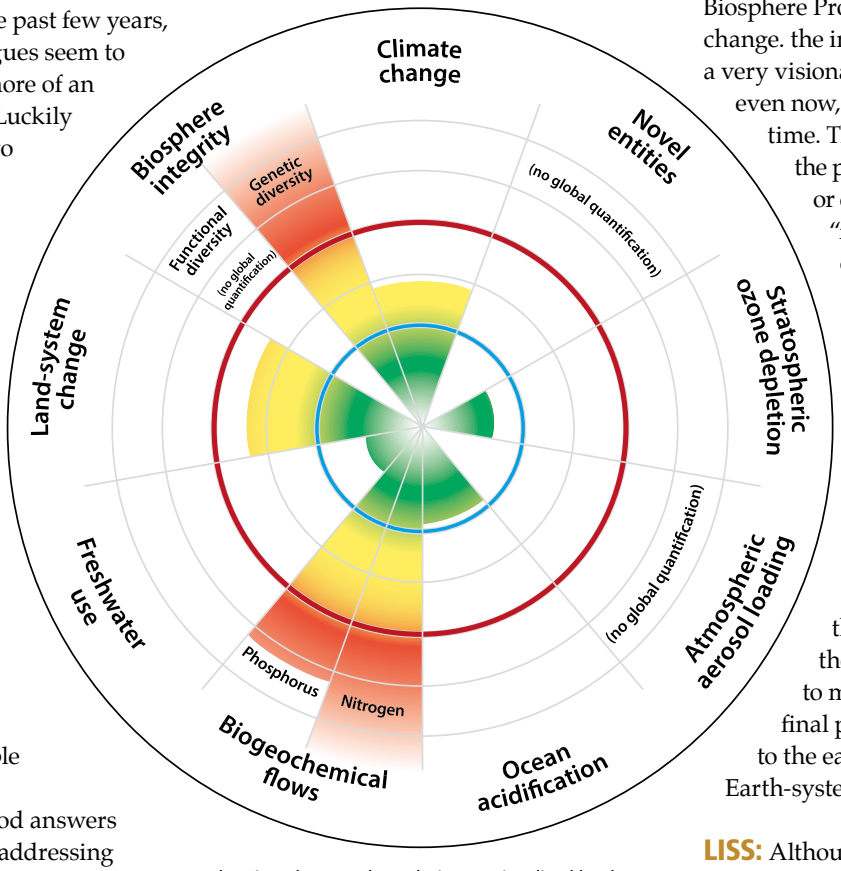
Working with a number of large private sector entities in recent years, I've often found myself playing the roles of "Issue Advocate" and "Honest Broker" proposed by Roger Pielke, Jr. Initially I found these roles to be somewhat discomforting. I struggled (as I still do) with trying to find the sweet spot at which I can express clear opinions about policy or decision options without losing my credibility as an impartial scientist (or being perceived as doing so). I've got more comfortable with this dilemma over the past few years, but now notice that colleagues seem to regard me as being even more of an oddball than I used to be. Luckily for me, I don't really have to care about this perception within the academic community. It does, however, shine a light on some conundrums we need to resolve.

For example, is it possible for any individual to occupy all of these roles without compromising his or her ability to fulfil any one of them? How do we empower stakeholders to assume the kind of influence that transdisciplinary efforts require without risking turning research into simple consultancy?

I certainly don't have good answers to these questions. Maybe addressing them should be a priority in the next evolutionary steps of Earth-system science.

SEITZINGER: We need to work with both "top down" (policy and societal questions/needs) and "bottom up" (science) approaches. Co-design is important but everything doesn't need to be co-designed. We must continue to advance the fundamental understanding of the functioning of the Earth system. This includes, of course, integration within and across spatial scales (local to regional to global) and in particular on time frames that are relevant to society – keeping in mind not only the near future, but multiple future generations. A grand challenge is integrating across the social, economic and biogeophysical domains.

SYVITSKI: Earth-system science is here to stay. It will continue through the IGBP core projects that are now part of Future Earth and through the larger academic community and their research societies. There will be a continuing role for global Earth observations and for assessments on rivers, coasts, polar regions and more. Post IGBP, there will certainly be a need for a focused international body to coordinate Earth-system science. Perhaps Future Earth will be able to play that role. And perhaps the space agencies and the larger international data efforts will also be able to provide needed coordination and focus. I remain optimistic that the internationally acclaimed achievements of IGBP will continue through the efforts of individuals and smaller teams as well as larger focused institutions, many of which have been established to mirror the organisational science structure of IGBP.



The nine planetary boundaries, as visualised by the Stockholm Resilience Centre/Globaïa. Source: Steffen *et al.* (2015) *Science*

Q: Any other thoughts or closing comments?

STEFFEN: As we reflect back on the history of IGBP and celebrate its achievements, it is very important to recognise the incredibly important foundation for the programme that was established during the planning phase in the late 1980s and the people who drove that. The best piece of evidence for the creative thinking on which the programme was founded is IGBP Report 12 ("The International Geosphere-Biosphere Programme: A study of global change. the initial core projects"). This is a very visionary and inspiring document even now, but was especially for its time. Those of us who have had the privilege to serve as chairs or directors owe much to the "founding fathers and mothers" of IGBP, and particularly to Thomas Rosswall. Without Thomas's dedication, energy and skill, the programme would never have had the excellent foundation on which it built so much over the years.

RAPLEY: What a disaster that the IGBP Secretariat is being jettisoned. The thinking behind this (was there any?) is incomprehensible to me, especially given the final points in my response to the earlier question on where Earth-system science goes from here!

LISS: Although IGBP and other such programmes often appear to be top-down organisations, some of the most successful activities have arisen spontaneously and in a bottom-up fashion. As a seminal NASA report from 1986 put it, "This insight has set the stage for a more complete and unified approach to its study, Earth System Science". ∎

Photo credits for opening photographs: Philip Wade (Liss, Steffen); Franz Dejon (Noone); Stefan Tell (Seitzinger); IISD (Rosswall); OneWorld (Rapley); Allen Krughoff (Syvitski)

Growing with IGBP

Pauline Dube, one of IGBP's vice-chairs, serves as a link between the African and global research communities studying climate and environmental change. Her career has been shaped strongly by her work with IGBP; in some ways her story is the story of IGBP itself.

Pauline Dube began her research career as a student using remote-sensing data to study land degradation in her native Botswana. Today, as an associate professor at the University of Botswana and a vice-chair of IGBP, Dube studies land-use and land-cover change, the veld fires and climate-change impacts, vulnerability and adaptation across Africa and beyond.

She has spearheaded global-change initiatives, in the process mentoring and providing opportunities for other researchers while forming a vibrant international research community. Most important, she has brought the perspective of developing countries to the work of IGBP and helped to integrate the natural and social aspects of global change.

Joining the IGBP community

Dube's first encounter with IGBP and issues of global change was in 1992 at the first Africa and Global Change meeting in Niamey, Niger. She recalls a presentation linking particulate matter from savannah fires in Africa with the subsequent formation of high ozone concentrations over the Atlantic Ocean. "Really, that just captivated me," Dube says. "I thought, wow, we really do have a global impact!"

In the 1990s, she says, "there were not so many of us" using remote sensing, particularly in African landscapes. She hypothesises that's why Thomas Rosswall, then Director of the IGBP Secretariat in Stockholm, encouraged her to work with IGBP. Rosswall persuaded her to establish an IGBP National Committee – IGBP was striving to be a truly global network at that time – which became the Botswana Global Change Committee (BGCC), and included natural and social aspects of global change.

Through this committee, Dube was to play a significant role in initiating global-change research in Africa. In 1994, she facilitated the first START[1] Regional Workshop, "Global Change in Southern, Central and Eastern Africa", in Botswana. But Dube wanted more than a committee for Botswana. "I felt there was a need to have a scientific project to tie us together, not just a committee," Dube says.

To that end, Dube and her colleagues explored the concept of terrestrial transects[2], championed by IGBP's Will Steffen and others. The result was the Kalahari Transect project, to run from South Africa through Botswana, all the way to the Democratic Republic of Congo. "We needed all the different scientists in different countries to work together – it was a challenge," she says.

The Kalahari Transect project created a robust interactive platform that drew scientists from different parts of the world. Dube recalls a crucial turning point at the African Savannahs and the Global Atmosphere meeting in 1993, in Victoria Falls, Zimbabwe, where she met Chris Justice, a high-profile remote-sensing scientist. At the time, Justice was based at the University of Virginia (he is now at the University of Maryland) and engaged in the IGBP's Data and Information Systems (IGBP-DIS) project[3].

With Justice's encouragement, Dube joined an international team of scientists in the IGBP/IHDP Land Use and Cover Change (LUCC) project, drafting the Miombo Network Terrestrial Transect

Fire and landscapes have been an important topic of Pauline Dube's research during her time with IGBP.

Science Agenda in Zomba, Malawi, in 1995, as part of LUCC[4]. The Miombo Network focused on understanding the effects of global change on the Miombo woodlands and land-use systems of Central Africa, and vice versa.

Parallel to this, START and IGBP combined efforts to establish Africa Regional Networks to encompass the breadth of the different ecosystems on the continent; Dube represented the START Southern Africa Committee (START SAFCOM) at the START Regional Committee for North Africa. For the first meeting in Malawi, in those pre-Internet days, she recalls having to wait weeks to receive information on meeting arrangements.

Around this time, apartheid was coming to an end in South Africa. "Still, some scholars couldn't tolerate that we were going to work with 'white' South Africans," Dube says. "We had many differences but at no time did anyone think of quitting. Everyone was committed and clear that studying and understanding global change in the African context was significant, so despite the dynamics between the scientists, the group kept going."

More work, more connections

While she was busy connecting researchers and organising large scientific programmes in Africa, colleagues began to encourage Dube to pursue doctoral research. For her post-graduate diploma and M.Phil. degree in 1989, at the University of Twente in the Netherlands and then at the University of Cranfield (UK) respectively, Dube had assessed land degradation in the rangelands of southeastern Botswana, comparing data from the newly launched SPOT satellite with LANDSAT data.

Her opportunity to follow up on that work came in 1994, with a grant from the International Agricultural Research Centre in Australia, to look at cattle ranching with CSIRO scientists in Alice Springs. While working there, Dube also enrolled at the University of Queensland to pursue doctoral research on human-induced change in the unique Okavango Delta in Botswana, now listed as the 1000th UNESCO World Heritage site. Dube continued linking her colleagues in Botswana with a network of scientists established through IGBP and START, and after finishing her PhD in 2000, she returned home to teach remote sensing at the University of Botswana.

In 1999, while still a student, Dube was invited to assist with the section on desertification in Africa, a controversial subject in the 1990s, for Working Group II of the Intergovernmental Panel on Climate Change (IPCC). "I remember thinking I was going to only assist for a little while, only to find it was a lifelong commitment," she jokes. For the fourth IPCC assessment, she was lead author on the ecosystems chapter and became a coordinating lead author for a special report on managing risks of climate change. She then served as a review editor for the fifth report of the IPCC Working Group II, as one of almost 100 individuals from the IGBP community to be part of the assessment.

Participating in the IPCC can be hard work with little recognition in the academic world, Dube says, but "I

Wendy Broadgate

> **"Science means being objective.**
>
> It also means using the past and the present to look ahead. Sometimes society wants something now and doesn't realise it may need something else 50 years from now. As scientists we need to be visionary, if you like, not only to address today's problems but also to address problems that might arise in the future. Science and policy must work together."

was excited to be one of the scientists who received a Nobel Peace prize certificate in 2007." A celebration organised by the UN Development Programme spotlighted her work, "almost getting me to the category of celebrity," she says with a laugh.

A fiery pursuit

In 2000, as Dube was finishing her PhD, several projects were about to catch fire through BGCC, the IGBP national committee. That work would further increase her connections to IGBP and other international efforts.

Working with Justice, Dube quickly became involved with the Southern Africa Fire Atmosphere Research Initiatives of 2000, dubbed SAFARI2000, which kicked off with a meeting at the University of Botswana facilitated by the BGCC. SAFARI2000 brought together leading international scientists interested in studying greenhouse gases, aerosols and pollution. The huge research campaign required specialised aircrafts and large groups of researchers crossing international borders. "To arrange for them to fly over required negotiations with governments," Dube says, plus facilitating research permits, meetings and more.

I was excited to be one of the scientists who received a Nobel Peace prize.

As the SAFARI2000 campaign drew to a close, Justice was working through the Global Observation of Forest Cover–Global Land Cover Dynamics (GOFC-GOLD) to put together a group to validate fire data in Southern Africa, fuelled by the launching of the MODIS instrument aboard NASA's Terra and Acqua satellites. Justice and others thought Dube would make a good leader of this group, given her remote-sensing background, and experience with START and IGBP.

At its first meeting in Botswana, the validation group became the Southern Africa Fire Network (SAFNet), hosted by the University of Botswana under BGCC. Dube coordinated SAFNet from 2000 to 2007, as the network grew from six countries to include all 14 Southern African Development Community countries.

In addition to data validation, SAFNet expanded to include policy and community fire-use challenges. "You need to understand why people [are starting burns] even when fire is a hazard, especially if you are going to come up with policy recommendations," Dube says. She set up SAFNet country contact points and encouraged rotating venues among the member countries for their meetings, while making sure policymakers attended. The majority of scientists who served as the SAFNet country contact points have made significant progress with their careers.

The work with SAFNet presented some non-scientific challenges too, Dube says. First the network had no funding. Dube needed to use persuasion and good communication to bring together international and regional fire scientists, policymakers and NGOs working with on-the-ground communities; to inspire and motivate the group; and to come up with a focused science agenda. The emergence at the same time of a Sub-Saharan fire network also called on her diplomatic skills "to make sure we were not wasting time on unproductive battles," she says. With few scientists on the ground, the two networks had to work together. Eventually, GOFC-GOLD introduced the SAFNet model to Australia and

Southeast Asia, to motivate the formation of similar networks.

Dube worked for SAFNet as a volunteer while holding a full-time job at the University of Botswana. Notably, when she left the network after seven years, four people took over her tasks.

Leading from the front

In 2008, Dube was appointed to serve on IGBP's Scientific Committee. After being involved in various IGBP-related activities for over a decade, this was her first foray into overseeing the programme's scientific and institutional development. Two years later she was appointed as one of IGBP's vice-chairs.

In this capacity Dube had the chance to work with Carlos Nobre, then Chair of IGBP, and João Morais, then Deputy Director for Social Sciences. The two scientists hailed from the global South – Brazil and Mozambique respectively – and Dube felt she had found like-minded colleagues. Together, they spearheaded a synthesis topic on global change and the needs of least developed countries (LDCs), which was embraced by IGBP and its networks. "We thought we needed to contribute something that directly addressed the developing world," she says.

The majority of the world's more than 40 LDCs are in Africa, with a few in the Asia-Pacific region. Getting funding was difficult, for poor regions must rely on the developed world. In the end, Dube says, the process was mixed: IGBP was able to secure funding for the Asia-Pacific component of the project but not for the African one.

"In Africa the problem is that despite all-out effort since the days of Rosswall and START, we failed to establish a strong Africa-wide network to work on global change," Dube laments. "Something similar to the Asia-Pacific Network for Global Change Research, which works to support individuals from developing countries from that part of the world, would have worked wonders."

Looking to the future

With IGBP set to close at the end of this year, Dube is wrapping up her work with an organisation that has been a professional home. "When you ask me about IGBP, you basically ask about my whole career, I have been so into it. All the science and networking activities I was involved in were strongly linked to IGBP. Even just the teaching – getting the material, getting satellite data, knowing whom to contact – has benefited from IGBP-linked networks," Dube says.

Still, Dube could see the need for a change. She was part of the visioning process launched in 2010 by the International Council for Science, IGBP's sponsor, that laid the foundation for re-organising internationally coordinated global-change research. This process and subsequent discussions "gave birth to Future Earth", Dube recalls. "I attended a couple of very hot meetings on these issues. These were difficult times – I had lived with IGBP for so long that it was hard to think about ending the organisation where I had spent much of my professional life."

And yet, as she went through the LDCs synthesis, for example, it was clear that IGBP needed to become more transdisciplinary in its orientation and develop even stronger links with the social sciences.

For now, Dube says, she has been too busy with managing IGBP's closure to think much about Future Earth. But she voices concerns that the new incarnation of global-change research, despite having five hubs, has no substantial presence in the global South. "Capacity-building, something that IGBP has a very good record of, remains a big issue. A hub in South Asia or Africa, for example, would serve to draw international scientists to the developing world, creating a fertile environment," she says.

Before addressing these issues, Dube will spend the rest of 2015 celebrating the organisation that shaped much of her career. For her, the celebrations began in 2013, when IGBP's executive group and Secretariat met for the 26th Officers' Meeting in Botswana and also fêted 20 years of the BGCC. This fall at the annual American Geophysical Union conference in San Francisco, Dube will co-convene a session on adaptation, one of many scientific sessions and other events that will reflect on IGBP's legacy.

"Then maybe next year", she says, "I will start thinking about Future Earth." ▮

As recounted to NAOMI LUBICK.

When you ask me about IGBP, you basically ask about my whole career.

REFERENCES AND NOTES

1. START refers to the Washington, D.C.-based capacity-building non-profit organisation, SysTem for Analysis, Research & Training.
2. The transects were undertaken as part of IGBP's Global Change and Terrestrial Ecosystems (GCTE) project.
3. IGBP's Data and Information Systems (DIS) project was launched in 1993.
4. Land Use and Cover Change (LUCC) was launched in 1994 as an IGBP Core Project.

TIMELINE OF GLOBAL-CHANGE SCIENCE

UNEP 1972 –

WCRP 1980 –

Global-Change Programmes

Global Atmospheric Research Program (GARP) 1967-1988

ICSU launches IGBP

JGOFS

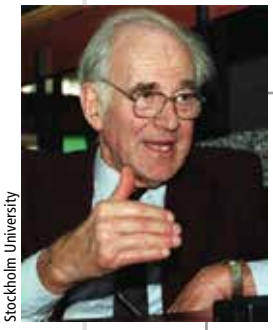
BAH

GCT

IGAC

GLOBAL CHANGE IGBP International Geosphere-Biosphere Programme 1986 – 2015

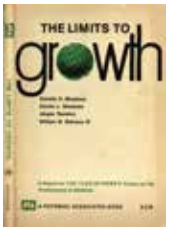
IGBP secretariat opens in Stockholm



Stockholm University

"Being at that time scientific advisor to the Swedish Prime Minister I was able to secure financial support from the Swedish government to develop this international research programme and to suggest the secretariat of the programme be located to Sweden. The Royal Swedish Academy of Science granted the project the use of its premises."

– Bert Bolin



Club of Rome publishes *Limits to Growth*

NASA publishes *Earth System Science Overview – A Program for Global Change*

WMO and UNEP agree to organise an intergovernmental assessment panel on climate change (IPCC)

IPCC publishes First Assessment Report

International Events

UN Conference on the Human Environment held in Stockholm

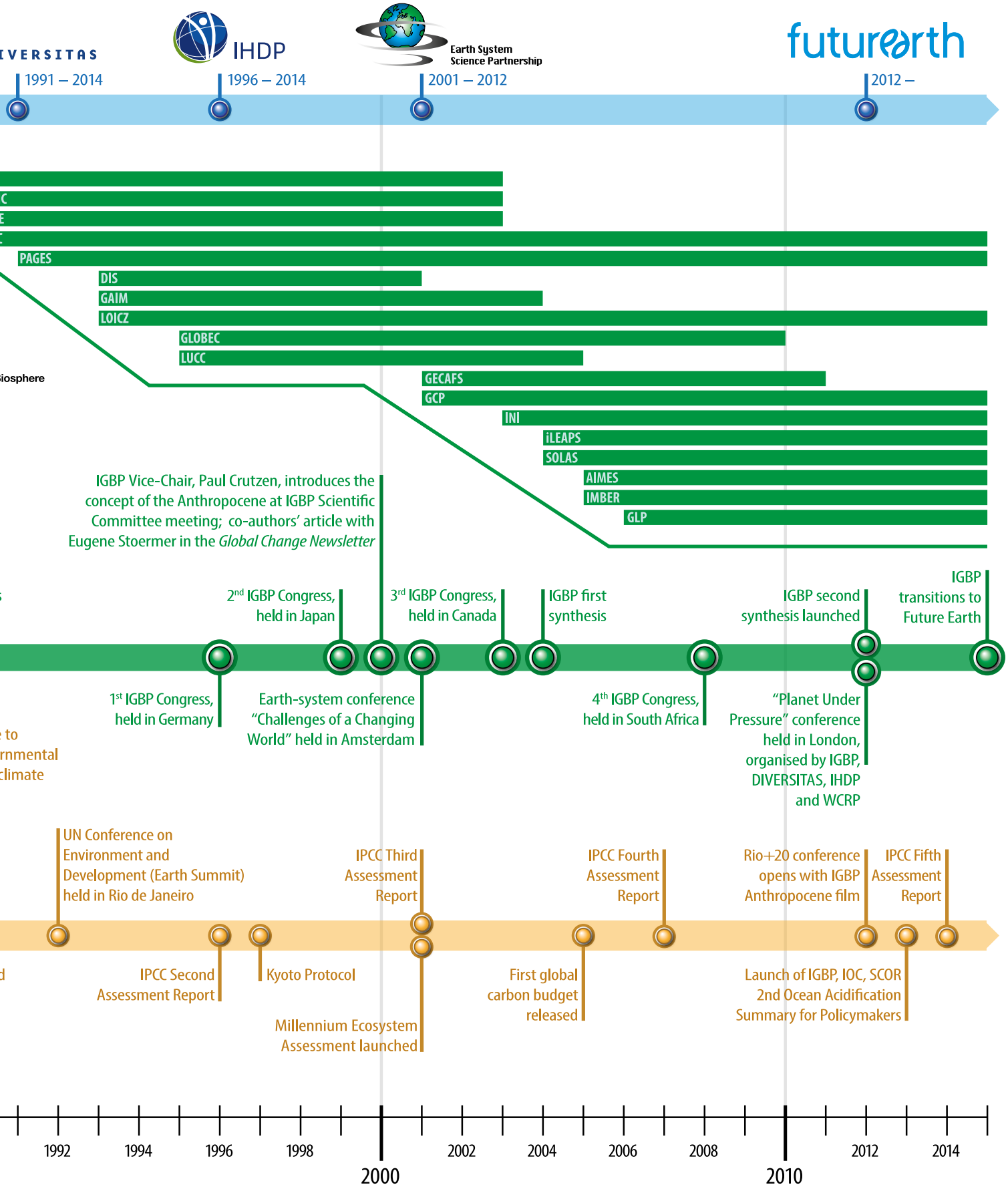
First World Climate Conference sponsored by WMO and UNEP

ICSU appoints committee chaired by Bert Bolin to plan an international research programme on the "global dimension of chemical and biological processes"

UN commission chaired by Gro Harlem Brundtland publishes *Our Common Future*

1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990

Timeline of some of the most significant events in the history of IGBP and other global-change programmes. The start and end dates of projects are based on project reports and websites and IGBP documents. For a complete listing of IGBP's core projects, see the back cover of this magazine.



ENGAGING POLICY: IGBP's three-decade legacy

Although IGBP has primarily contributed to knowledge creation and synthesis, it also has a robust track record of interacting with policy processes. **Ninad Bondre** and **Sybil Seitzinger** take stock of the programme's key contributions and how they have evolved during its three-decade history.

IGBP's first report[1] made it clear that "the purposes of IGBP are both fundamental and practical." The programme would focus primarily on understanding the Earth system and its response to human actions. Yet the report also emphasised the need for active involvement from the world's governments so as to use the knowledge generated by the programme to make policy and economic decisions. This was echoed in 1989 by the UN General Assembly resolution A/RES/44/207, which recommended that governments "increase their activities in support of the … International Geosphere-Biosphere Programme"[2].

The IGBP community has involved itself with policy processes ever since its launch, although the nature of this interaction has evolved through time. Whereas the early focus was on climate change, many other topics – biodiversity and ecosystems, ocean acidification and the Sustainable Development Goals, for example – have subsequently received attention, particularly during the last decade. Then there is the somewhat unsung story of our national committees all over the world. These committees have served as a crucial link between local/regional and global science, and helped to inform local and national policies.

Here we dwell briefly on IGBP's interaction with policy during its three-decade history. We focus on the efforts at the programme level coordinated by the Secretariat; individual projects informed policy too, some quite successfully, but we refer to only such interactions initiated by the projects that involved the IGBP Secretariat. Although by no means comprehensive, this review should serve to give a flavour of the efforts.

International assessments and conventions

The introduction to the 2009 review of IGBP[3] states: "The success and recognition of the Intergovernmental Panel on Climate Change (IPCC) and the Millennium Ecosystem Assessment (MA) both owe a huge amount to the work of IGBP." The IPCC, which was set up in 1988 – soon after IGBP launched – is indeed the poster child of the programme's engagement with policy (see Figure 1).

This engagement began quite early, which is not surprising given that the Swedish academic Bert Bolin, who was strongly involved in setting up IGBP, was also the first chair of the IPCC. IGBP and the World Climate Research Programme (WCRP) find prominent mention in several of the IPCC reports. For example, the Working Group I summary for policymakers of the IPCC's first assessment anticipated that the planned research endeavours of IGBP and WRCP would provide the observations and models that would help to reduce uncertainties[4]. Similarly, the Working Group II summary for policymakers foresaw three of IGBP's core projects providing valuable data in the years to come[5].

Minutes of IGBP's 1993 Scientific Committee meeting reveal substantial input to the IPCC's second assessment, which was published in 1995[6]. IGBP nominated authors and reviewers, provided specific advice on the content of some chapters and commented on the coordination between Working Groups I and II as well as on the frequency of assessments. The Working Group I report noted that IGBP and WCRP provided an international framework for climate studies and an international climate agenda. More recently, IGBP and WCRP were mentioned in the first sentence of the acknowledgements of Working Group I's report in the 2007 assessment.[7]

The interaction hasn't been only one way. The IPCC assessments themselves have informed the research and synthesis agendas of IGBP and its core projects. For example, in 2009 IGBP launched a series of synthesis topics that sought to address gaps in our understanding, identified in part by the fourth assessment report and in consultation with the IPCC[8]. IGBP and the IPCC have also conducted joint workshops: for example, two workshops in 2009 focused on the fifth assessment report and impacts, vulnerability and adaptation in developing countries, respectively. In 2013, IGBP organised a public event in Stockholm to communicate the findings from IPCC's fifth assessment to a broad audience[9].

Two important conventions were launched soon after the 1992 Rio Earth Summit: the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD). IGBP has contributed significantly to the former, particularly to its Subsidiary Body on Scientific and Technological Advice (SBSTA). For example, each year

The 2012 Planet Under Pressure conference fed into the UN's Rio+20 conference later that year. Here, Elizabeth Thompson (left), who was Executive Coordinator for the UN's Rio+20 conference and is a former Minister for Energy and Environment of Barbados, addresses a press conference as IGBP's Sybil Seitzinger looks on.

Photo: Philip Wade Photography

IGBP has been invited to annual research dialogues, where it has discussed the latest research findings on climate-related topics and sought feedback from governments. Moreover, IGBP organised a package of activities at COP15, which was held in Copenhagen in 2009. It put together side events, set up a booth and launched its climate-change index (see page 7).

Although the CBD has been less of a focus, which is understandable given IGBP's research agenda, it has nevertheless received important inputs from IGBP-related activities. For example, a publication resulting from a synthesis on the ecosystem impacts of geoengineering informed aspects of a 2012 report of the CBD[10]. IGBP's Surface Ocean-Lower Atmosphere Study (SOLAS) had a key role in developing a summary for policymakers on ocean fertilisation to inform the CBD and other processes. The IGBP Secretariat, via its liaisons, followed the drafting process and also ensured wide distribution of the final product.

Ocean acidification and carbon

IGBP's review in 2009, while noting the programme's previous input to policy, nevertheless stated that the programme "should consider as a matter of urgency how to maximize the scientific, policy, and practice impacts of IGBP-related science". Taking this review seriously, IGBP diversified its engagement with policy. A prominent success story of the past six years or so is its role – along with partners such as the Scientific Committee on Oceanic Research (SCOR), the International Oceanographic Commission (IOC) and UNESCO – in bringing ocean acidification to the centre of the international policy agenda.

IGBP has been co-sponsoring symposia on the ocean in a high-CO_2 world since 2008. In 2011 IGBP and its partners published a summary for policymakers on this topic[11]. This summary, one of the first of its kind and available in several languages, was distributed widely. The 2012 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. An updated summary, emerging from the 2012 symposium, was released in November 2013 at the UNFCCC climate talks in Warsaw[12].

IGBP had revamped its communication team following the 2009 review; this team set about raising the profile of ocean acidification in international media outlets that would be likely to be read by key policymakers. Findings from the 2012 symposium, for example, attracted headlines in *The Economist*, *The Washington Post* and other outlets. In view of the rapid developments in our understanding of ocean acidification, IGBP and partners set up an ocean acidification portal in 2014 to inform policymakers and others about the latest findings[13].

The Global Carbon Project (GCP), co-sponsored by the four global-change programmes through the Earth System Science Partnership, has been producing carbon budgets since 2007[14]. During the past few years, the IGBP Secretariat has worked with the project to ensure that the budget receives wide publicity. Not only has it targeted prominent media outlets for news articles but also arranged for commentaries in top journals. It has also advised GCP on the Global Carbon Atlas, a user-friendly interface to visualise and access data on all aspects of the carbon cycle, a tool that is aimed at policymakers, researchers and the general public[15].

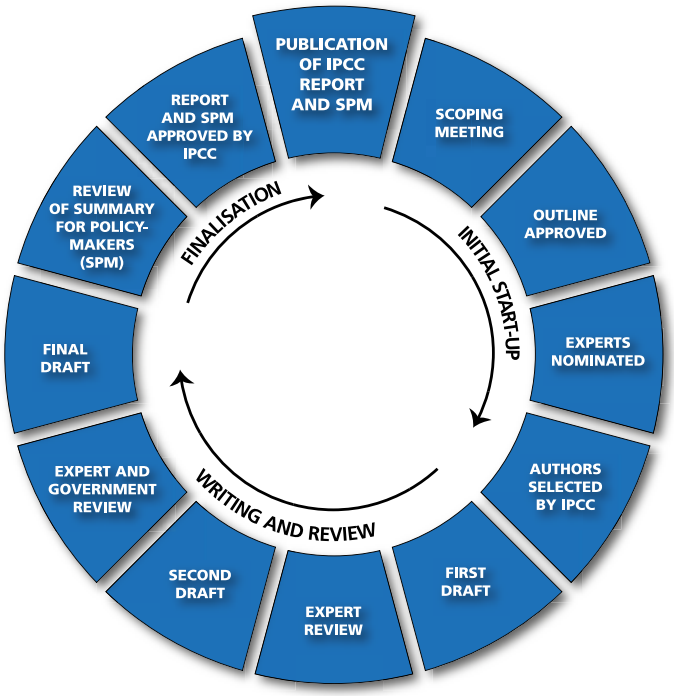


Figure 1. The IPCC assessment cycle. The IGBP community interacts with IPCC in various ways: IGBP/affiliated scientists participate in scoping meetings, nominate experts and contribute to drafting and reviewing the report itself. The IGBP Secretariat advises during the outline and review stages, identifies new directions for the next report and nominates authors and reviewers. IPCC and IGBP hold joint meetings throughout the assessment process and, in the recent past, have coordinated their communications efforts.

IGBP organised a package of activities at COP15.

Rio+20 and the Sustainable Development Goals

IGBP led the organisation of the 2012 Planet Under Pressure conference in London together with its sister global-change programmes and ICSU. The conference, with its overt emphasis on solutions, was acknowledged by the UN as the major scientific conference in support of its Rio Conference on Sustainable Development (Rio+20) to be held later that year.

IGBP and its partners invested special effort on engaging policymakers along with representatives of businesses from all over the world. In this respect the conference has served as a model for subsequent conferences. Planet Under Pressure, in addition to activities that preceded and followed it, placed IGBP in a strong position to inform the emerging Sustainable Development Goals (SDGs).

In 2010 IGBP had established contact with the UN Secretary-General's chief climate advisor and published an interview with him in the *Global Change* magazine[16]. The following year, the IGBP Secretariat organised a workshop on planetary stewardship that included a senior advisor to the Secretary-General's High Level Panel on Global Sustainability. Such activities put the SDGs firmly on IGBP's agenda and that of the Planet Under Pressure conference. Indeed, the first science-policy dialogue on SDGs took place at the Conference.

The IGBP Secretariat led the development of a series of policy briefs targeted at Rio+20 that drew on white papers emerging from the London conference[17]. A short film on the Anthropocene developed by IGBP served to launch Rio+20, and Ban Ki-moon referred to the State of the Planet declaration emerging from the Planet Under Pressure conference[18]. These efforts were complemented by commentaries and opinion pieces relevant to the SDGs in high-profile journals[19].

Towards Future Earth

Future Earth has made co-design and co-production of knowledge the central pillar of its approach. It seeks to engage a wide range of stakeholders including policymakers, and is seeking to target processes such as the SDGs. IGBP's experience, particularly during the past few years, provides a strong foundation that Future Earth can build on.

As discussed above IGBP, particularly during its most recent phase, established links with diverse policy processes at the international level. This insured that it could maximise the relevance of the information produced by its many core projects. Future Earth will inherit this network as well as other networks from former programmes such as the International Human Dimensions Programme on Global Environmental Change (IHDP) and the biodiversity programme DIVERSITAS. This network is capable of informing many processes in addition to the SDGs, which have been the focus of recent Future Earth efforts. Future Earth would thus do well to engage with as broad a set of policy processes as feasible.

IGBP has provided inputs to Future Earth, both via regular discussions as well as via a taskforce on policy that was set up to advise Future Earth's leadership. Moreover, many individuals closely associated with IGBP are now in leading positions at Future Earth and the global-change research community is expected to participate actively in this initiative. Many ingredients for its success are thus in place.

A stable and well-resourced secretariat backed up by a strong communications team was critical to the success of IGBP's policy engagement; this was fully supported by the programme's scientific committee. The Secretariat was able to have a bird's- eye view on developments within various projects and networks, distil relevant findings and communicate those to the right audiences. In our view Future Earth will need its distributed secretariat to be similarly well staffed, resourced and coordinated to implement its ambitious agenda.

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The iconic images of Earth beamed back by the earliest spacecraft helped to galvanise interest in our planet's environment. The subsequent evolution and development of satellites for Earth observation has been intricately linked with that of IGBP and other global-change research programmes, write **Jack Kaye** and **Cat Downy**.

IGBP and Earth observation: a co-evolution

Going back to 1987, when IGBP was created, there was much we did not know about our home planet. The discipline of Earth-system science – the study of Earth as a connected system – was in its infancy, having been proposed by NASA in its 'Bretherton Reports'[1]. The modern era of satellite observations had only recently begun; scientific disciplines as well as the international community were much less integrated than they are today. The models that Earth scientists used to describe Earth's behaviour and its future changes were much more "component-based". Moreover, the international assessments that help to unite the community and distil enormous amounts of information into forms usable for scientists and policymakers were just getting under way: the WMO/UNEP ozone assessments did not gather steam until the mid-1980s, whereas the IPCC was not set up until 1988. That we find ourselves in a very different situation today is due in no small part to the efforts of the IGBP scientific community.

Satellites began to observe our planet in the 1970s.

New technology, new uses

Satellites began to observe our planet in the 1970s; the first passive microwave images were taken from NOAA's Nimbus 5 in 1972, swiftly followed by measurements of ocean colour and ozone from instruments on Nimbus 7. TIROS-N gave us the first in the long-running AVHRR sensor series and an atmospheric sounding system. Early developments in this field were led by the United States, but planning for Europe's ERS-1 satellite began in 1977: it was to observe water and ice to plug what was then a major data gap.

By the mid-1980s Earth-observation data were of sufficiently long duration to allow scientists to look at interannual variability. This is when the research community really started making significant use of these data. The Landsat 5 satellite that was to become a major source of global land-cover data was launched in 1984 – the same year that the Committee on Earth Observation Satellites (CEOS) was set up to coordinate and harmonise observations to facilitate access to and use of data. Today, the space agencies participating in CEOS have more than 100 Earth observation missions in orbit (www.ceos.org).

Many other satellites that provided new views of the Earth did not launch until shortly after the creation of IGBP – the Upper Atmosphere Research Satellite (UARS) in 1991 and Topex/Poseidon in 1992 are just two examples – each of which also represented international collaborations. The European Space Agency (ESA) launched its European Remote Sensing (ERS) satellites ERS-1 and ERS-2 in 1991 and 1995, respectively. Japan's first Advanced Earth Observing Satellite (ADEOS-1) was launched in 1996. Planning for NASA's Earth Observing System (EOS) had begun around the time, building towards launches of satellites such as Terra, Aqua and Aura in 1999, 2002 and 2004, respectively. Satellite observations were integrated with field campaigns that combined surface-based and airborne observations. The First ISLSCP Field Experiment (FIFE), set up in 1987, was one of the earliest field campaigns

Landsat 8 image of the Rio Mamoré in the Amazon Basin in 2014.

NASA Earth Observatory images by Jesse Allen, using Landsat data from the U.S. Geological Survey.

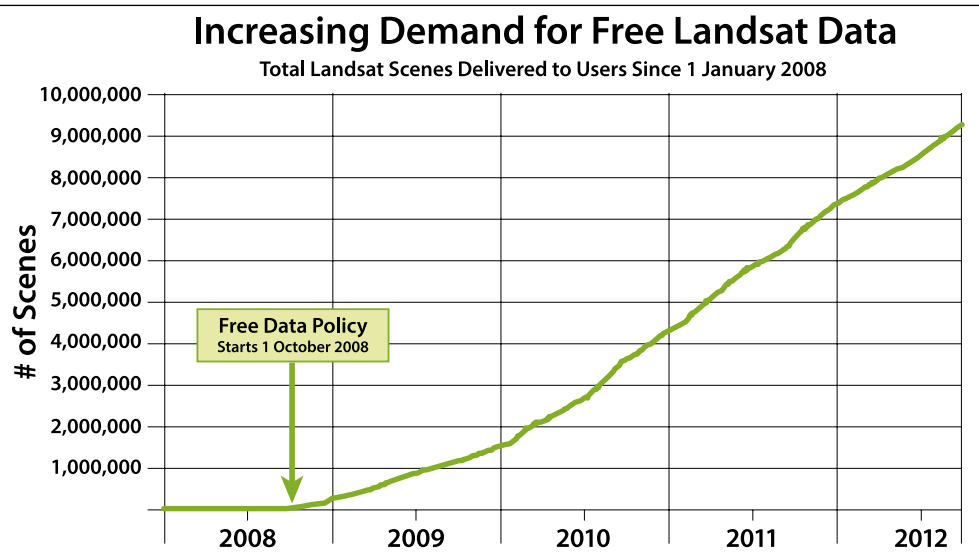

Figure 1. Landsat downloads. Beginning 1 October 2008, Landsat data could be downloaded freely. This had an immediate impact: the number of scenes downloaded increased manifold during the next few years. (NASA's Goddard Space Flight Center and the U.S. Geological Survey. http://svs.gsfc.nasa.gov/vis/a010000/a011400/a011458/)

that integrated both satellite and field data to study Earth-system behaviour. Other examples include the Boreal-Ecosystem-Atmosphere study in the US and Canada (1994-1996); the Large-scale Biosphere-Atmosphere Experiment in Brazil that began in 1998 (but for which planning started in 1993; see box); the polar ozone airborne campaigns in the Antarctic (1987) and Arctic (1989, 1992); and Global Troposphere Experiment (GTE) series of airborne campaigns going back to 1983 and continuing into the early 21st century.

In 1993 IGBP launched its Data and Information System (IGBP-DIS) project to help develop critical data sets and enable effective data-management systems. At the time of its inception, access to Earth observation data wasn't easy and was very costly, which limited the extent to which satellite data could contribute to research. Together with CEOS, IGBP-DIS spearheaded an initiative to gather key data sets identified by the community at a reduced price from the space agencies. The resulting 1km AVHRR data set was one of the main driving forces in improvements in global land data sets. Subsequent work resulted in the development of data principles in support of the operational use of satellite data for public benefit. The first freely available medium-resolution imagery dates to 2004, and access to Earth-observations data has improved greatly since then. In particular, the decision in 2008 to release the current and archived Landsat data encouraged far more people to use the data than before (Figure 1). The commitment from many space agencies to free and open data policies continues today, as demonstrated by the recently agreed policy for Copernicus' Sentinel data and the release of the highest-resolution topographic data from NASA's Shuttle Radar Topography Mission (SRTM).

Convening communities, setting agendas

As the scientific community put this new observing capability to use, it led to research into some very visible and societally important topics: the Antarctic ozone hole discovered in the mid-1980s was actively investigated and the large 1987–1988 El Niño event (followed by a large La Niña event) provided particular foci for interdisciplinary observational and modelling studies. We came to measure the increasing rate of ice loss from the polar regions and regional rates of sea-level rise. Making sense of all these data and figuring out what they meant for the planet's future required sophisticated Earth-system models. IGBP – by virtue of its ability to bring together different disciplines, communities and nations – was at the forefront of the development of models that combined physics, chemistry and biology. Such models now include realistic representation of the Earth's carbon cycle and associated biology and biogeochemistry.

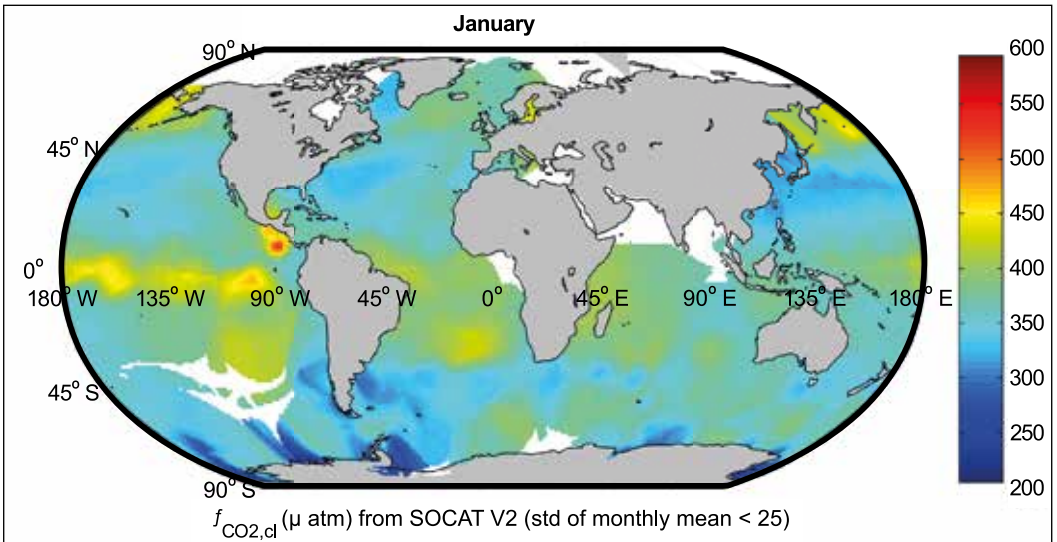

Figure 2. The ESA-SOLAS OceanFlux Greenhouse Gases project used satellite data to re-analyse Surface Ocean CO_2 Atlas (SOCAT) measurements, enabling the study of global CO_2 atmosphere-ocean gas fluxes (Goddijn-Murphy *et al.* 2015 *Ocean Sciences* 11: 519-541, doi:10.5194/os-11-519-2015).

The LBA legacy

The Large-scale Biosphere-Atmosphere Experiment in Amazonia (LBA) is a multinational, interdisciplinary research programme led by Brazil through its Ministry of Science and Technology. Its goals are to understand how Amazonia functions as a regional entity in the Earth system and how those functions are responding to ongoing changes in land use and climate. The LBA as a research programme grew out of a demand from scientists linked to the IGBP. Given this linkage, the LBA can be understood as a product of IGBP in conjunction with other research programmes that operated in the region. Its institutional relationship with the IGBP research effort on global change directly affected the formulation of its research questions, design and institutional arrangement. LBA scientific activities cover seven themes: (1) land-use and land-cover change, (2) physical climate, (3) carbon dynamics, (4) biogeochemistry, (5) atmospheric chemistry, (6) land-surface hydrology and aquatic chemistry, and (7) human dimensions. LBA research has contributed to the advance of scientific understanding and expansion of technical and human capacity to help frame local and national development and conservation issues. Integrating bottom-up and top-down measurements has been a key aspect of LBA. Socio-economic drivers related to logging, ranching, farming, and infrastructure have been integrated into land-use models, which have been used as effective tools for demonstrating scenarios and trade-offs of future land cover, carbon stocks, water resources, conservation and economic development. Remote-sensing tools have been developed and operationalised to improve monitoring of deforestation rates, logging activity and forecasting of regional air pollution. Beyond specific research findings, LBA research has contributed to the process of framing development and conservation issues with up-to-date science through a deliberate planning process that fostered interdisciplinary science and training and education. A new generation of young South American scientists has been trained to develop and use these tools and their underlying science.

– Mercedes Bustamante and Michael Keller

IGBP not only provided a forum for model development but also facilitated inclusive model-model and model-observation intercomparison activities.

IGBP's convening capacity is unparalleled: it played a particularly important role in bringing increased international participation into the NASA-initiated Northern Eurasia Earth Science Partnership Initiative (NEESPI) by endorsing it as an External Project in 2006. With this broader support NEESPI has become a highly successful programme. "The global research programmes have been vital in improving the interface between Earth observation and the Earth-system science community and in making sure the science community can get full value from the ESA programme," says Stephen Briggs, Senior Advisor to ESA's Earth Observation Programme, who initiated a Research Fellowship jointly between ESA and IGBP. "Input from the global change programmes helped enormously in orienting ESA satellite and applications development programmes, such as the recently selected Earth Explorer mission, BIOMASS. The IGBP community has played a significant role in setting the agenda for Earth-system science, and guiding ESA's priorities in the exploitation of satellite data." Dedicated joint projects between ESA and IGBP, such as the OceanFlux projects between ESA and the Surface Ocean-Lower Atmosphere Study (SOLAS; Figure 2), have helped strengthen this interface with Earth-system science researchers.

Looking back at its founding documents, the authors of "Toward an IGBP"[2] realised that "progress in understanding global change will require extensive and well-organised observations made over much of the Earth and over a long period of time." Good progress has been made in coordinating and broadening Earth observation product use but it is crucial that we continue to do this in partnership with Future Earth. We hope Future Earth will combine the strong emphasis on advancing fundamental physical and biological science that IGBP and its partners have nurtured with increasing global efforts to use that knowledge to improve the quality of life for all the world's citizens.

The space agencies and scientific community all owe a debt to those who contributed their time and effort towards making IGBP such a valuable contributor to, and resource for, the Earth-system science community.

The IGBP community has played a significant role in setting the agenda for Earth-system science.

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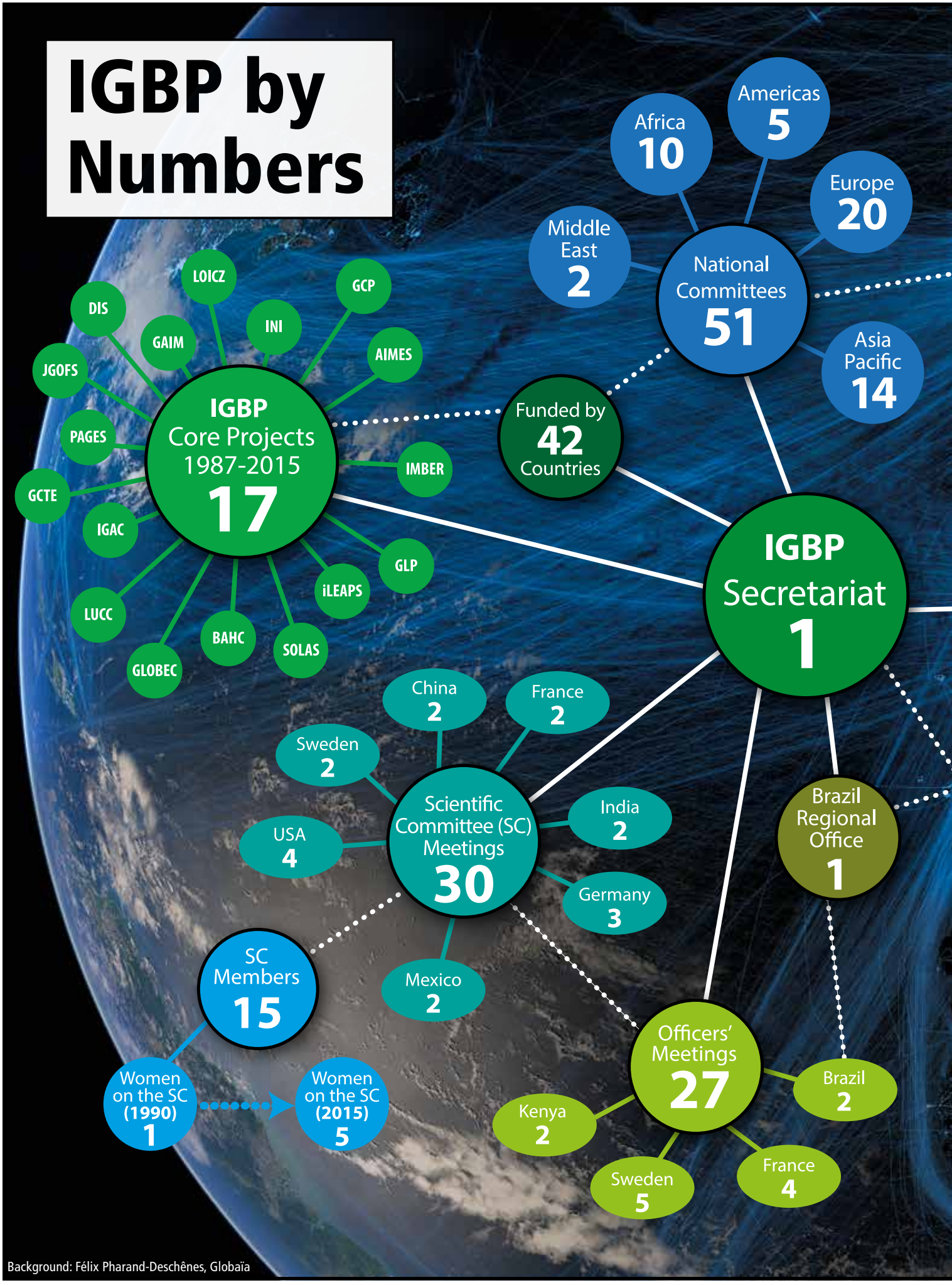
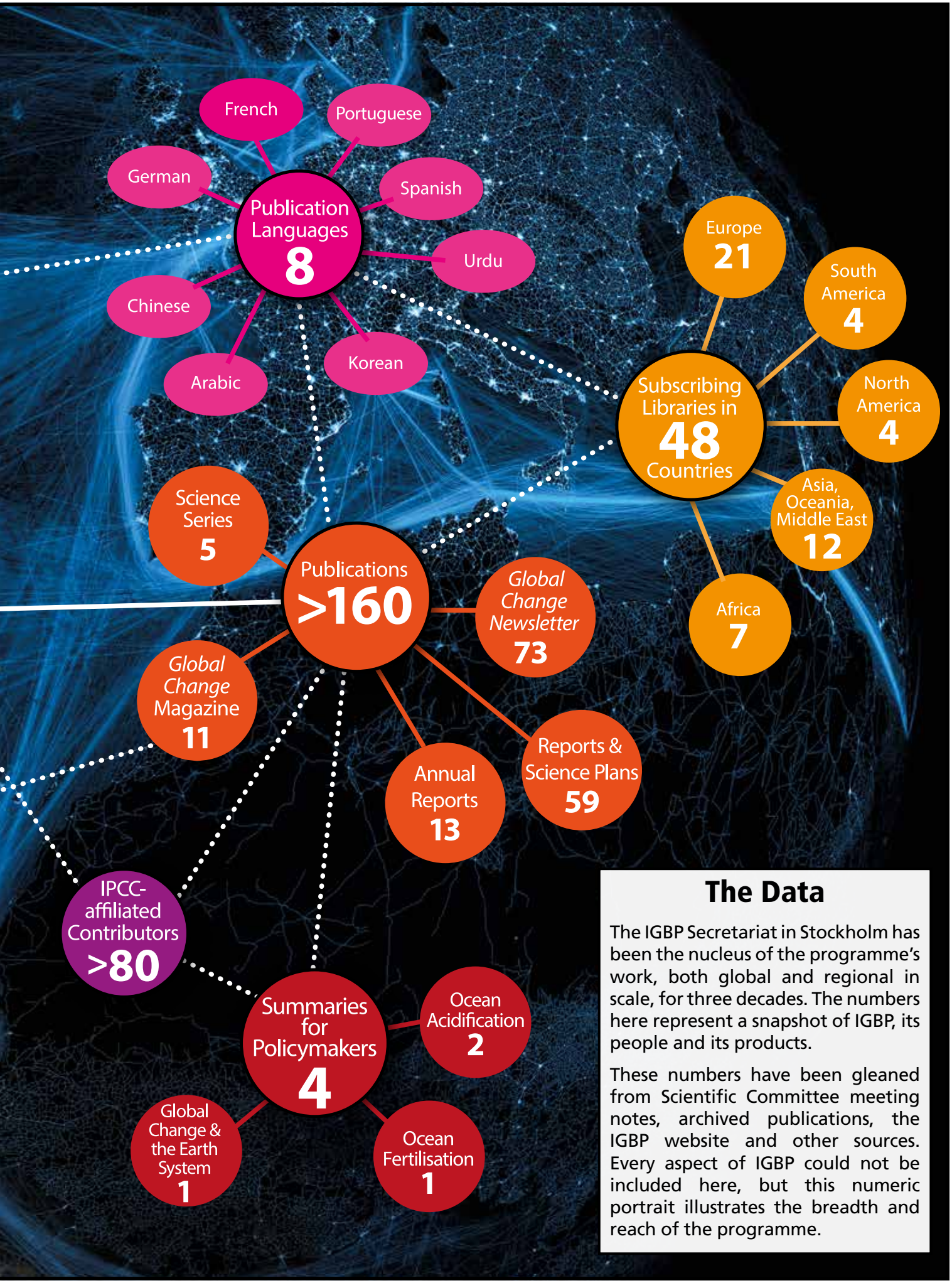


Background: Félix Pharand-Deschênes, Globaïa



The Data

The IGBP Secretariat in Stockholm has been the nucleus of the programme's work, both global and regional in scale, for three decades. The numbers here represent a snapshot of IGBP, its people and its products.

These numbers have been gleaned from Scientific Committee meeting notes, archived publications, the IGBP website and other sources. Every aspect of IGBP could not be included here, but this numeric portrait illustrates the breadth and reach of the programme.

A personal note on IGBP and the social sciences

Humans are an integral component of the Earth system as conceptualised by IGBP. **João Morais** recalls key milestones in IGBP's engagement with the social sciences and offers some words of advice for Future Earth.

In the first volume of his autobiography published in 1952, the Hungarian-British author and journalist Arthur Koestler wrote of a revolutionary crisis that was rapidly demolishing all familiar assumptions of thought. Having lived through major historical convulsions associated with the pre- and post-world wars, Koestler – who was briefly a science editor during his writing career – pondered whether the state of matter, and of life, ultimately, would converge. As he wrote, "Philosophy is the gaseous state of thought, Science its liquid state, Religion its rigid state."

The meteoric path of global-change research represents Koestler's convergence. The seeds of this research were sown by the race to put a man on the moon in the 1960s, a development that was as political as it was technical. The era of space exploration provided a philosophically as well as visually powerful porthole to our blue planet. Seeing the planet as a whole highlighted its fragility and hence the necessity of some kind of governability. Perhaps that is why the term "global change" emerged in the 1970s from the political-science community. This term would soon be superseded by "Earth-system science", best illustrated by the so-called Bretherton diagram that was developed in 1986 for a NASA advisory council report[1].

Erik Huss

Humans occupied a marginal position in the geocentric Bretherton world.

Humans occupied a marginal position in the geocentric Bretherton world. But despite such marginalisation, this conceptualisation of the planet and its functions spoke to the plea for a human agenda to address "our common future".[2] Perhaps under the sway of this ideal, IGBP initially flirted with normative issues such as governance, commonly associated with the social sciences. But IGBP also saw itself as a "neutral forum": its leadership pointed out that the Human Dimensions Programme – which at the time represented the social-science research relevant to global change – was closely related to policy and that IGBP should "avoid being drawn into politics".[3]

I joined IGBP in 1995 initially as the Social Sciences Officer, after having been involved with human and natural science studies as an archaeologist. I soon realised, with much disappointment, that global-change research in fact reflected parallel scientific worlds. There was even a "social process diagram" designed to match its Bretherton counterpart[4] and, for a short time, duplicate HDP offices in Barcelona and Geneva, reminding us of the Avignon versus Rome papal schism. I was nevertheless encouraged by the opportunity that the IGBP agenda offered to challenge the two-culture syndrome, particularly through projects such as Past Global Changes (PAGES) and Land Use and Cover Change (LUCC). The work of these projects clearly demonstrated how biogeochemistry, climate and land-cover change have interacted with the human sphere in space and time. I was keen to do more.

My opportunity came when the International Council for Science (ICSU) and the International Social Science Council (ISSC) – sponsors of IGBP and the Human Dimensions Programme, respectively – initiated closer collaboration. In 1996, I participated in exciting discussions in which two opposing views emerged: one camp argued for integrating both programmes under the IGBP umbrella while the other wanted to group the human sciences into a separate programme. Unfortunately, the timing wasn't ripe to allow those two asymmetrical communities to merge. A separate programme, the International Human Dimensions Programme on Global Environmental Change (IHDP), was set up after substantial effort and negotiations. I recall a critical dinner where ICSU General Secretary J W M La Rivière, Eckart Ehlers and I brainstormed on how IHDP could have a home at the University of Bonn, where Ehlers was Professor of Geography.

Despite the missed opportunity to integrate, some IGBP communities and its Secretariat strove hard to better incorporate the social sciences into the research agenda and find the required administrative infrastructure to run it. For example, the LUCC project engaged a broad community involving natural and social sciences. As Ola Uhrqvist notes,[5] this endeavour was not without its tensions: it wasn't always easy to reconcile different methodologies and perceptions of scales. Nevertheless, he states, "the project added new layers of complexity and non-linearity to IGBP's and IHDP's Earth System imaginary." And, like finding a home for IHDP, it took many negotiations and steadfast commitment from IGBP to have a core project office established at the Cartographic Institute in Barcelona.

Such developments helped cement the place of humans as integral components of the Earth system. Throughout the late 1990s, IGBP and its community were becoming more and more aware of the need for integration of the natural and social sciences. IGBP thus took the lead in organising the seminal Amsterdam open science conference in 2001, which was held jointly with the other global-change programmes. This would prove to be the trigger to set up the Earth System Science Partnership (ESSP). If, in its early phases, global change research suffered from an obvious attraction and bias in which Earth system's biophysical processes were seen as having a better "fit" at a global scale, the ESSP platform helped the science to come of age. ESSP raised awareness that global impacts on life-supporting systems and livelihoods were most critical at sub-global levels, where societal needs reside.

Based on my 17-year history with IGBP, I do not hesitate to underscore the critical role this programme played in advancing scientific integration and cross-disciplinary leadership, a fact that unfortunately finds little mention in a recent overview of the history of global-change research[6]. Had it not been so, concepts such as the Anthropocene, the Great Acceleration and global-regional integration would not have emerged as such central themes of IGBP's first synthesis. In the past decade or so, IGBP's projects such as the Global Land Project and Land-Ocean Interactions in the Coastal Zone (co-sponsored by IHDP) have ensured a continuing and vital role for the social sciences. In many ways, IGBP's trajectory over the past decade has set a strong foundation for Future Earth.

It took many negotiations and steadfast commitment from IGBP.

On Future Earth

The Future Earth scientific agenda and its broad leadership indicate the recognition of the common interests bridging science and society. However, we seem to have made little progress in bridging regional divides. Whereas the power of international partnerships has received much attention, the more modest but valuable place-based research done in the developing world (see page 14 of this issue) tends to escape attention. Regrettably, making headway into unravelling the carbon cycle seems easier than conducting science that is participative and based on a shared global responsibility. But a real push towards global sustainability can only be achieved by overcoming the "us" and "them" of separate or incompatible worldviews and agendas. The minutes of early IGBP Scientific Committee meetings suggest that there was, from the outset, the desire to see a strong regional presence via regional research centres and national committees. Whereas some progress was made, scarce resources meant that many of these remained mere platforms and fora for presentations on IGBP and geo-biosphere observatories. In spite of geopolitical interests that led to the establishment of regional networks in Africa, Latin America and Asia, such initiatives had (and arguably still have) poor articulation within the global-change programmes' priorities. Future Earth should do better.

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Towards Future Earth: evolution or revolution?

During its three decades of existence, the International Geosphere-Biosphere Programme (IGBP) built research networks, facilitated synthesis and enhanced capacity around the world. Its trajectory may offer some pointers for Future Earth as it charts its own course.

Earlier this year we spent a lot of time in the archives of the Royal Swedish Academy of Sciences – a fascinating, if somewhat cramped, place in the basement of this 18th century building. Among other things, we were making sure that valuable documents, some dating to the years prior to IGBP's founding, were in good shape. It proved hard to resist being drawn into the letters, faxes, reports and newsletters that traced the origin and early evolution of IGBP. Naturally, it set us thinking about Future Earth and the course it will chart during the coming decade. The early IGBP was somewhat different from Future Earth, but its more recent phase can certainly be viewed as a stepping-stone for the new initiative.

IGBP was set up in 1986 with an ambitious goal of "providing the information we need to assess the future of the Earth in the next 100 years"[1]. The programme was to gain a fuller understanding of the Earth as an interconnected whole. It would focus on such aspects as biogeochemical cycles, which were not being looked at by existing programmes or activities. There seems to have been an explicit desire to go beyond disciplinary confines: indeed, the word "transdisciplinary" pops up on the very first page of the first report that can be attributed to IGBP[1]. Early documents also make it clear that the programme was not about knowledge for knowledge's sake but about informing decisions and policies.

Nothing quite like IGBP had been in operation in the mid-1980s.

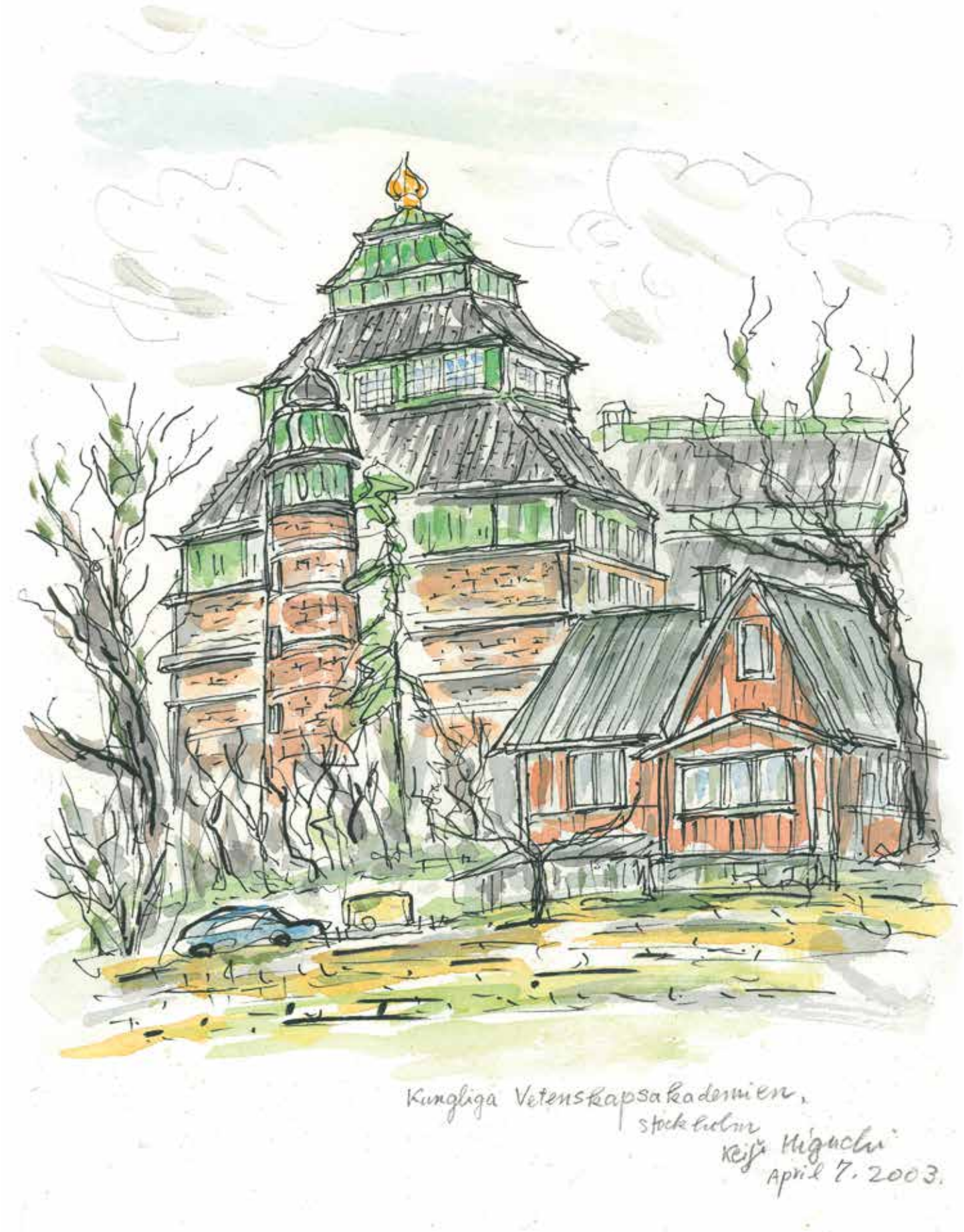
Nothing quite like IGBP had been in operation in the mid-1980s and the anticipated level of international scientific coordination and collaboration was, in some respects, unprecedented. Below we trace some of the key institutional developments during the programme's lifetime. The picture that emerges is of an adaptable and flexible organisation that did not hesitate to change in the face of changing scientific and societal realities.

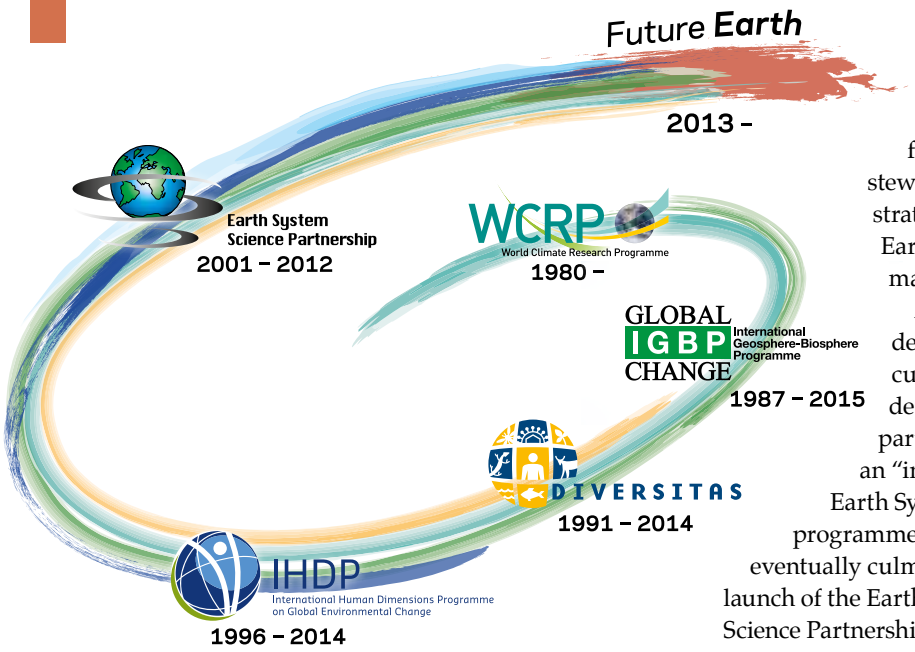
From Amsterdam to London

The decade between 1990 and 2000 witnessed the setting up and maturing of several core projects that addressed almost all dimensions of the physical Earth system. National committees were set up in many countries around the world. The Secretariat in Stockholm became a well-oiled unit for coordination and communication. More and more satellite data were being generated, major scientific cruises and expeditions were being undertaken: for example, the Joint Global Ocean Flux Study organised cruises in all the major ocean basins. Computing power was increasing and the Internet had begun revolutionising communication. All of this translated into significant knowledge production at the project as well as programme level.

In many ways, IGBP's trajectory is also that of the refinement and further evolution of the concept of the Earth system. Various components were described in more and more detail, and the interactions among these were elucidated. There was growing recognition of feedbacks, thresholds and rapid, or sudden, irreversible changes. Before IGBP came into existence, much of the research on climate had tended to focus on its physical aspects. IGBP's projects focused explicitly on how life – terrestrial and marine ecosystems – interacted with the physical and chemical systems.

By the late 1990s the scientific leadership became keenly aware of the need for a programme-wide synthesis to complement project-level syntheses that had already begun. At the same time, the community was also beginning to have a greater


Kungliga Vetenskapsakademien,
Stockholm
Keiji Higuchi
April 7. 2003.



Earth-system science entered a new phase in 2001, when the four major global-change programmes came together. The communities belonging to three of the programmes will now work under the Future Earth umbrella.

appreciation of the degree to which humans had altered and were continuing to alter their environment – in fact, humans were an integral component of the Earth system as a whole. Indeed, the Anthropocene concept – first introduced by Paul Crutzen and Eugene Stoermer in the *Global Change Newsletter*[2] – featured prominently in the programme-wide synthesis, which sought to quantify it by means of the now-iconic Great Acceleration graphs.

The Global Change Open Science Conference, held in Amsterdam in 2001 and jointly organised by IGBP, the International Human Dimensions Programme on Global Environmental Change (IHDP) and the World Climate Research Programme (WCRP), marked the beginning of a new era for IGBP. The conference highlighted the research of the programmes as well as the emerging outcomes of IGBP's first synthesis. It also explored the pathway that Earth-system science would take in the following decade. The conference is perhaps best remembered for the "Amsterdam Declaration", which stated unequivocally that anthropogenic forces were "equal to some of the great forces of nature in their extent and impact"[3]. Furthermore, the declaration calls for "an ethical framework for global stewardship and strategies for Earth system management".

Understanding the Anthropocene required a more integrated approach.

All of these developments culminated in a desire on IGBP's part to create an "integrated Earth System Science programme"[4]. This would eventually culminate in the launch of the Earth System Science Partnership (ESSP) made up of IGBP, WCRP, IHDP and DIVERSITAS. The formation of ESSP meant that carbon, water, food security and health would now be looked at by projects sponsored jointly by the four programmes.

IGBP research during the 2000s responded to the growing recognition that humans were the prime driver of change on the planet. Understanding the Anthropocene required a more integrated approach to the Earth system and thus greater emphasis on interdisciplinarity. This interdisciplinarity was reflected both within a core project as well as in increased interaction among core projects. The human dimensions were brought in more explicitly and there was greater engagement with stakeholders. Climate became a more prominent component of many core projects' scientific agendas and there was greater interaction with the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC).

In 2009, the International Council for Science (ICSU) and the International Group of Funding Agencies (IGFA) published their review of IGBP[5]. The review team, while acknowledging the programme's significant contributions to science and policy, recommended that IGBP maximise its impacts on science, policy and practice. The team emphasised that "in setting future scientific priorities within IGBP-related activities, finding solutions to practical problems must feature much more strongly than IGBP has hitherto been mandated".

The review also alluded to the increasingly more complex landscape of global-environmental-change research. Noting the "increasingly unwieldy and confusing arrangements among the Programmes, and between them and ESSP", the review team stated that "most people contributing evidence to this review do not believe that there should be four GEC [Global Environmental Change] Programmes with independent planning a decade from now". Soon after the review ICSU initiated a process of "Earth system visioning". The goal was to develop a ten-year effort to address challenges in global sustainability research.

IGBP revised its vision in response to the review: since around 2010, sustainability in the Anthropocene has taken on a larger role in framing its science and activities. It has continued to study Earth-system processes, but with an emphasis on the applicability and relevance of this knowledge. It called on the UN to take a more integrated view of its over 500 international treaties and conventions that address the environment[6]. It invested substantially on communication and the science-policy interface, targeting processes such as Rio+20, the Convention on Biological Diversity (CBD) and the Sustainable Development Goals, in addition to the ongoing emphasis on the UNFCCC and IPCC. It produced numerous policy briefs[7,8] and, in particular, helped to raise the profile of ocean acidification in policy arenas via conferences, and

through engagement in the International Ocean Acidification Reference Users Group (iOA RUG). It has worked closely with the Global Carbon Project to ensure that the findings of its annual carbon budget are communicated as widely as possible.

IGBP had also begun to focus on sustainability around this time and it recognised the need to create a new, more integrated community of natural and social scientists as well as various stakeholders. In 2010, IGBP launched a synthesis on specific topics identified by IGBP's scientific committee with input from key stakeholders, including other international research programmes and IPCC. The synthesis sought to involve scientists from many disciplines as well as policymakers and other stakeholders. This led to, for example, greater emphasis on exploring the links between air pollution and climate[9]; a review on the ecosystem impacts of geoengineering[10]; and an assessment of the socioeconomic consequences of, and responses to, global environmental change in least developed countries[11].

In 2010 IGBP initiated the planning of the second major global-change conference, Planet Under Pressure. This conference – which involved the three other global-change programmes as well as ICSU itself – was the largest gathering of scientists and others interested in global change. The IGBP Secretariat, along with its partners, made an unprecedented effort to bring together diverse communities of scientists, policymakers and practitioners from across the world for the conference, which was held in London in 2012. This community would provide the nucleus for Future Earth, the new initiative on global sustainability that was the outcome of ICSU's visioning process. As with the Amsterdam Conference, Planet Under Pressure also led to a declaration – the State of the Planet Declaration. The conference raised some difficult questions too, particularly for traditional Earth-system scientists, which were summarised by the late Mike Raupach in his article for the *Global Change* magazine[12]. Raupach called for a path ahead that combines "the need for wide engagement with a continuing commitment to reason".

Towards Future Earth

The original goals of IGBP remain at least as valid today as they were three decades ago. However, much has changed in the world and in our understanding of it since IGBP launched. In the early days of IGBP, Earth-system science took centre stage: it evolved from a focus on individual elements to a focus on interconnections. The intervening years have brought to the fore the concept of the Anthropocene and, with it, the recognition of a radically altered human-environment relationship. The Anthropocene lens brings forth the interconnections among various social and ecological processes.

The present calls for an even closer interaction among various disciplines and with stakeholders than IGBP was able to accomplish. It also calls for a new way of doing, communicating and using science. This, in part, provides the rationale for Future Earth. During the past few years IGBP and its projects have made a conscious effort to deepen engagement with social scientists. The projects have also revised their science plans to address the growing emphasis on policy relevance, stakeholder engagement and co-design and co-production. Most projects are thus set to bring their communities under the Future Earth umbrella. It remains to be seen how existing, focused research communities such as IGBP's core projects are able to buy into and adapt to the new model.

It also calls for a new way of doing, communicating and using science.

IGBP's longevity and success can be attributed, among other things, to its visionary leadership, dedicated community, bottom-up organising and capacity to adapt its scientific and institutional agenda to changing circumstances. IGBP's history – via its excellent archives as well as the experience of its foot soldiers – will be available to guide Future Earth as it gathers steam. ▮

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GLOBAL CHANGE
IGBP International Geosphere-Biosphere Programme

ICSU International Council for Science

IGBP is an ICSU global-environmental-change programme.

IGBP core and joint projects and activities 1987-2015

Joint Global Ocean Flux Study (JGOFS) 1989-2003
Biosphere Aspects of the Hydrological Cycle (BAHC) 1990-2003
Global Change and Terrestrial Ecosystems (GCTE) 1990-2003
International Global Atmospheric Chemistry (IGAC) 1990-
Past Global Changes (PAGES) 1991-
Data and Information Systems (DIS) 1993-2001
Global Analysis Integration and Modelling (GAIM) 1993-2004
Land–Ocean Interactions in the Coastal Zone (LOICZ) 1993-
Global Ocean Ecosystem Dynamics (GLOBEC) 1995-2010
Land Use and Cover Change (LUCC) 1995-2005
Global Carbon Project (GCP) 2001-
International Nitrogen Initiative (INI) 2003-
Integrated Land Ecosystem–Atmosphere Processes Study (ILEAPS) 2004-
Surface Ocean–Lower Atmosphere Study (SOLAS) 2004-
Analysis, Integration and Modelling of the Earth System (AIMES) 2005-
Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) 2005-
Global Land Project (GLP) 2006-
Global Water System Project (GWSP) 2004-

Future Earth

Global-change research continues with Future Earth, a ten-year international research initiative. See futureearth.org for more information.