

Developing a common strategy for integrative global environmental change research and outreach: the Earth System Science Partnership (ESSP)

Strategy paper

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The Earth System Science Partnership (ESSP) was established in 2001 by four global environmental change (GEC) research programmes: DIVERSITAS, IGBP, IHDP and WCRP. ESSP facilitates the study of the Earth's environment as an integrated system in order to understand how and why it is changing, and to explore the implications of these changes for global and regional sustainability. Joint research projects on carbon dynamics, food, water and health have been established. As a result of an independent review, the ESSP developed a new strategy that will provide an internationally coordinated and holistic approach to Earth system science. The approach integrates natural and social sciences from regional to the global scale. The mainstay of the ESSP is to identify and define Earth system science challenges, enable integrative research to address these challenges, and build scientific capacity. The GEC research community also faces an increasing challenge to present research results in more accessible and informative ways to stakeholders, especially to policy-makers. In response, the ESSP is developing new services that include knowledge products, Earth system science fora, a synthesis journal and interdisciplinary collaborative research. Coping with GEC is an enormous challenge and one the world must respond to successfully. Our common goal is, therefore, to develop the essential knowledge base needed to respond effectively and quickly to the great challenge of GEC.

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The science of global environmental change

Many human activities now match (and often exceed) the natural forces of the Earth system [1^{••}]. Recent ice core data show that current levels of carbon dioxide and methane are outside the range of natural variability over the last 800 000 years [2]. Roughly half of the ice-free land surface has been altered by human actions [3^{••}]. Humans now fix more nitrogen than nature does in terrestrial systems [4[•]]. Emissions from human activities alter the energy balance of the planet, as well as have adverse effects on human health [5^{••}]. Human choices about the resources we use and the manner in which we use them are at the heart of many of these changes. These may seem to be unrelated issues. However, over the past decades we have gained a deeper understanding of the degree to which all of these separate issues are linked [6]. It is this interconnectivity and the unprecedented scale of the human trans-

formation of the Earth system that calls for a new paradigm in the way science seeks to understand global environmental problems and to provide solutions.

The kinds of questions now being asked of the research community by policy and decision-makers have changed over the past decades reflecting the increasing appreciation of the interconnectedness of the Earth system [6,7]. As researchers tackled scientific questions of societal importance initial investigations were led by individuals from distinct scientific disciplines; later some of the harder questions could be successfully addressed by concentrating on either individual or a small number of the components of the Earth system, although a full response to such questions requires international, interdisciplinary collaboration. For example, establishing the cause–effect relationships of the Antarctic ozone hole required international collaboration amongst atmospheric chemists, meteorologists and remote sensing experts. All such innovative interdisciplinary research efforts increased understanding, helped develop adequate solutions to these problems and enabled decision-makers to take decisions based on the best scientific information available.

The challenges we face today on local, regional and global environmental changes (GECs) can only be addressed with a close coupling of approaches from both the natural and social sciences. Effective responses will also require new observational, modelling and synthesis approaches that, to a much larger extent, have to integrate the many different dimensions of the biosphere, the pedosphere and the anthroposphere [6,7]. In short, the complexity of the scientific problems that our generation and future ones to come need to address will continue to increase. The demand and urgency for decisions and solutions will also continue to grow, and the GEC research community will have the challenge and commensurate opportunity to respond to such needs in a timely and effective manner.

Rationale for an integrative Earth System Science Partnership

The need for an international, multidisciplinary approach to respond to challenges and opportunities associated with GEC research is not new. The World Climate Research Programme (WCRP; <http://wcrp.wmo.int/>) was established in 1980 in response to the need for a framework within which to organise and facilitate international climate research to understand and to predict the Earth's climate system, and to decipher the role of humans in this context. The International Geosphere–Biosphere Programme (IGBP, <http://www.igbp.net/>) was initiated in 1987 with the intention to better link the biological and physical sciences and research communities. The International Human Dimensions Programme on Global Environmental Change (IHDP; <http://www.ihdp.org/>) was founded in its current form in 1996 and succeeded the Human Dimension Programme that existed from 1991 to 1996. IHDP supports

Box 1 Definitions and Global Environmental Change Research Programmes

Definitions

Global Environmental Change (GEC) includes changes in the physical and biogeochemical environment, either caused naturally or influenced by human activities such as deforestation, fossil fuel consumption, urbanisation, land reclamation, agricultural intensification, freshwater extraction, fisheries over-exploitation and waste production.

The *Earth system* is the unified set of physical, chemical, biological and social components, processes and interactions that together determine the state and dynamics of Planet Earth, including its biota and human occupants.

Earth System Science is the study of the Earth system, with an emphasis on observing, understanding and predicting global environmental changes involving interactions between land, atmosphere, water, ice, biosphere, societies, technologies and economies.

GEC research programmes

DIVERSITAS — an integrated programme of biodiversity science

The mission of DIVERSITAS is to promote an integrative biodiversity science, linking biological, ecological and social disciplines in an effort to produce socially relevant new knowledge; and to provide the scientific basis for the conservation and sustainable use of biodiversity.

IGBP — International Geosphere–Biosphere Programme

The vision of the IGBP is to provide scientific knowledge to improve the sustainability of the living Earth. IGBP studies the interactions between biological, chemical and physical processes and how they impact (and are impacted by) with human systems.

IHDP — International Human Dimensions Programme on Global Environmental Change

The IHDP is dedicated to promoting, catalysing and coordinating interdisciplinary research on the human dimensions of global environmental change. IHDP takes a social science perspective on global change and it works at the interface between science and practice.

WCRP — World Climate Research Programme

The major objectives of the WCRP are to determine the extent to which climate can be predicted, and to determine the extent of human influence on climate.

international multidisciplinary research in the social sciences and humanities. DIVERSITAS (an international programme of biodiversity science) (<http://www.diversitas-international.org/>) was launched in its current structure in 2001 to build a global programme in biodiversity science. Each of these GEC research programmes is highly international and multidisciplinary in scope (Box 1). All these programmes have the International Council for Science (ICSU; <http://www.icsu.org/>) as a common sponsor.

However, in the late 1990s it became apparent that these programmes could not individually address the Earth

Box 2 The Amsterdam Declaration on Global Change

The scientific communities of four international global environmental change research programmes — IGBP, IHDP, WCRP and DIVERSITAS — recognise that, in addition to the threat of significant climate change, there is growing concern over the ever-increasing human modification of other aspects of the global environment and the consequent implications for human well-being. Basic goods and services supplied by the planetary life-support system, such as food, water, clean air and an environment conducive to human health, are being affected increasingly by global change.

Research carried out over the past decade under the auspices of the four programmes to address these concerns has shown that:

- The Earth system behaves as a single, self-regulating system comprising physical, chemical, biological and human components. The interactions and feedbacks between the component parts are complex and exhibit multi-scale temporal and spatial variability. The understanding of the natural dynamics of the Earth system has advanced greatly in recent years and provides a sound basis for evaluating the effects and consequences of human-driven change.
- Human activities are significantly influencing Earth's environment in many ways in addition to greenhouse gas emissions and climate change. Anthropogenic changes to Earth's land surface, oceans, coasts and atmosphere and to biological diversity, the water cycle and biogeochemical cycles are clearly identifiable beyond natural variability. They are equal to some of the great forces of nature in their extent and impact. Many are accelerating. Global change is real and is happening *now*.
- Global change cannot be understood in terms of a simple cause-effect paradigm. Human-driven changes cause multiple effects that cascade through the Earth system in complex ways. These effects interact with each other and with local-scale and regional-scale changes in multidimensional patterns that are difficult to understand and even more difficult to predict. Surprises abound.
- Earth system dynamics are characterised by critical thresholds and abrupt changes. Human activities could inadvertently trigger such changes with severe consequences for Earth's environment and inhabitants. The Earth system has operated in different states over

the last half million years, with abrupt transitions (a decade or less) sometimes occurring between them. Human activities have the potential to switch the Earth system to alternative modes of operation that may prove irreversible and less hospitable to humans and other life. The probability of a human-driven abrupt change in Earth's environment has yet to be quantified but is not negligible.

- In terms of some key environmental parameters, the Earth system has moved well outside the range of the natural variability exhibited over at least the last half million years. The nature of changes now occurring simultaneously in the Earth system, their magnitudes and rates of change are unprecedented. The Earth is currently operating in a no-analogue state.

On this basis the international global change programmes urge governments, public and private institutions and people of the world to agree that:

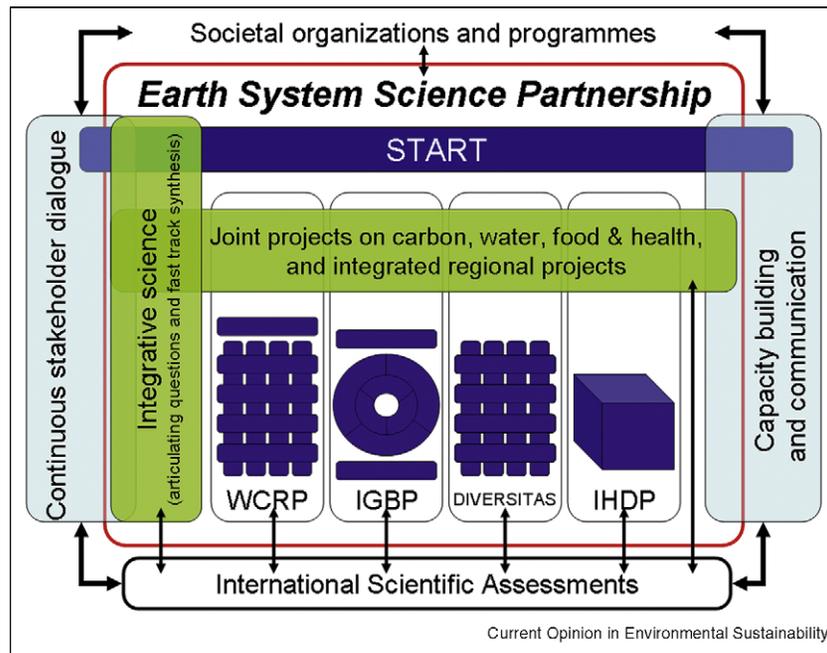
- An ethical framework for global stewardship and strategies for Earth system management are urgently needed. The accelerating human transformation of the Earth's environment is not sustainable. Therefore, the business-as-usual way of dealing with the Earth system is not an option. It has to be replaced — as soon as possible — by deliberate strategies of good management that sustain the Earth's environment whilst meeting social and economic development objectives.
- A new system of global environmental science is required. This is beginning to evolve from complementary approaches of the international global change research programmes and needs strengthening and further development. It will draw strongly on the existing and expanding disciplinary base of global change science; integrate across disciplines, environment and development issues and the natural and social sciences; collaborate across national boundaries on the basis of shared and secure infrastructure; intensify efforts to enable the full involvement of developing country scientists; and employ the complementary strengths of nations and regions to build an efficient international system of global environmental science.

system-level integrative questions, especially those that relate to fundamental issues of energy (carbon), food, water and health. These issues require knowledge that cannot be easily generated by 'conventional' research programmes dealing with components of the Earth system. A broader structure for GEC research was needed. Such a need was further addressed by the Amsterdam Declaration on Global Change (Box 2 [8]), which resulted from discussion amongst all programmes on future research issues at IGBP's 2001 'Challenges of a Changing Earth: Global Change' open science meeting. The declaration led to the establishment of the Earth System Science Partnership (ESSP; <http://www.essp.org/>) by the four programmes. As such, the Amsterdam Declaration recognised the solid foundation established by the pioneering GEC research programmes and identified the need for a new partnership to respond to the challenges associated with greater integration of emerging scientific knowledge of the Earth system and the need for timely information for decision-makers, hence the birth of the ESSP.

Earth System Science Partnership

The Earth System Science Partnership (ESSP) is designed to facilitate the study of the Earth's environment as an integrated system in order to understand how and why it is changing and to explore the implications of these changes for global and regional sustainability. The ESSP represents a concerted effort by DIVERSITAS, IGBP, IHDP and WCRP to establish a partnership that: (1) enables the community to identify and carry out research on scientific problems of high social and policy significance in a unified and integrative manner; (2) initiates and supports capacity building; (3) provides a high-level platform for effective engagement with stakeholders and the policy community; and, (4) facilitates efforts to ensure the continued vitality of the scientific enterprise (Figure 1). In acting as a partnership, the GEC research programmes ensure that their individual efforts are effectively leveraged and amplified and that they are able to concretely realize the scientific and social promise of Earth systems science. In essence, ESSP—as

Figure 1



ESSP's structure to facilitate transdisciplinary integrative science. Central to the partnership are the four individual GEC research programmes, each with their own structure, objectives and outreach, which themselves have a number of dual-GEC programme projects and which contribute significantly to the scientific assessments. Together, the programmes and ESSP, organise capacity building through START and engage in a dialogue to articulate the relevant Earth system questions, develop the necessary integrative science and inform society.

Box 3 ESSP Joint Projects

GCP – Global Carbon Project

The GCP was established in 2001 in recognition of the enormous scientific challenge and fundamentally critical nature of the carbon cycle for Earth sustainability. The scientific goal of the Project is to develop a complete picture of the global carbon cycle, including both its biophysical and human dimensions together with the interactions and feedbacks between them.

GECAFS – Global Environmental Change and Food Systems

The GECAFS goal is to determine strategies to cope with the impacts of global environmental change on food systems and to assess the environmental and socioeconomic consequences of adaptive responses aimed at improving food security.

GWSP – Global Water System Project

The GWSP aims to address the central research question: How are humans changing the global water cycle, the associated biogeochemical cycles and the biological components of the global water system and what are the social feedbacks arising from these changes?

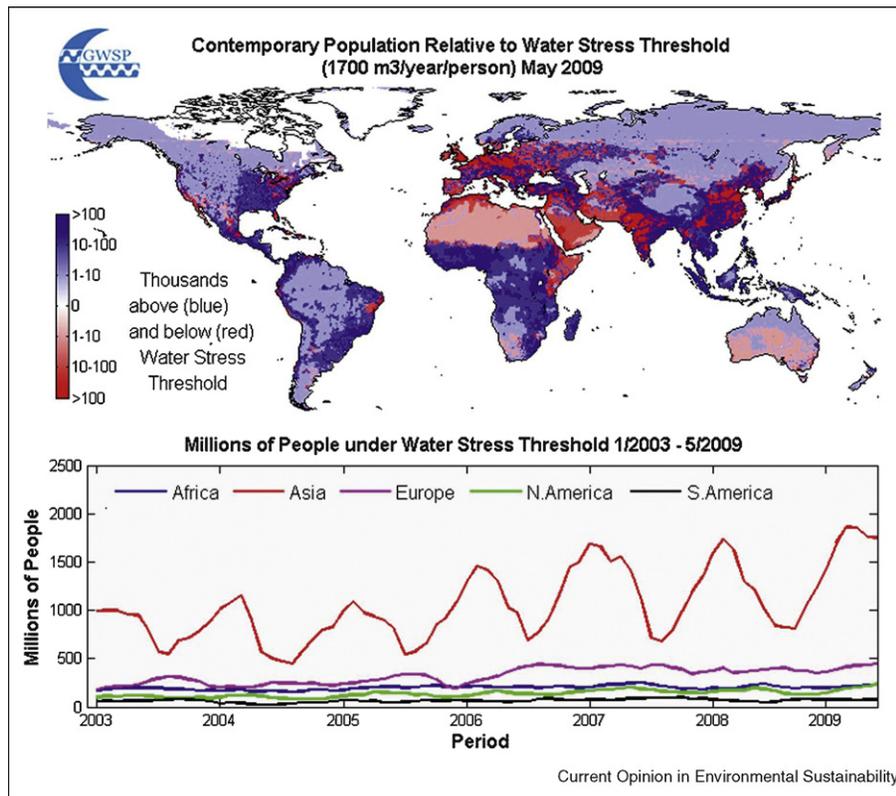
GECHH – Global Environmental Change and Human Health

Global Environmental Change and Human Health is the fourth joint project within the ESSP. It is being developed as a logical complement to the three ongoing ESSP projects, as changes in each of those three systems (food, carbon, water) influence, via diverse pathways, human well-being and health.

a partnership—thus provides a unique platform for DIVERSITAS, IGBP, IHDP, WCRP and the wider research community to coordinate and utilize their individual efforts to deliver substantially more integrated scientific knowledge of societal relevance to decision-makers.

One approach to demonstrate the additional value that this partnership offers, beyond contributions of its parent programmes, has been the continuation and establishment of ESSP Joint Projects related to GEC and sustainability on: first, the carbon cycle (GCP, Global Carbon Project; <http://www.globalcarbonproject.org/>); second, food systems (GECAFS, Global Environmental Change and Food Systems; <http://www.gecafs.org/>) third, water systems (GWSP, Global Water System Project; <http://www.gwsp.org/>) and (more recently) fourth, human health (GECHH, Global Environmental Change and Human Health; <http://www.gechh.org/>). These four joint projects (see Box 3 for more details) not only distil pertinent process-related research/knowledge from the core projects of individual partners, but also undertake research at global, regional and local scales that integrates knowledge into action-oriented products. They also cross the boundaries of social and natural sciences. The ESSP's Joint Projects offer a genuine home base for the new type of interdisciplinary (and transdisciplinary) researcher, who is so urgently needed to tackle today's global change and sustainability

Figure 2



The *State of the Global Water System* knowledge product, organised under the umbrella of the *Global Water System Project*, provides a set of electronic maps, which seek to represent a definitive, comprehensive and up-to-date picture of the state of the hydrologic systems and affiliated world water resources, their accessibility and use by society. The analysis here presents levels of water scarcity for the period January 2003–May 2009, dictated by the conjunction of climate variability and population.

challenges [9]. In the short time that they have been in operation, the joint projects have developed their own methodologies and approaches to build the scientific infrastructure that allows for a more integrated approach. For example, efforts being spearheaded through the GWSP are underway to operationalise the assessment of the condition of global water resources and their interaction with society (Figure 2). Another example is the timely annual updates on the global carbon budget and interpretation of its trends and changes by a small group of renowned experts [10,11] that has attracted great interest from the scientific and policy communities and generated impressive media coverage (Figure 3).

ESSP is also developing a small set of Integrated Regional Studies, designed to contribute sound scientific understanding in support of sustainable development at the local and regional level. These studies will also improve overall knowledge of regional–global linkages in the context of Earth system dynamics. The first such study is the Monsoon Asia Integrated Regional Study (MAIRS; <http://www.mairs-essp.org/>), which attempts to understand to what extent human activities modulate the Asia monsoon climate and how the changed monsoon climate

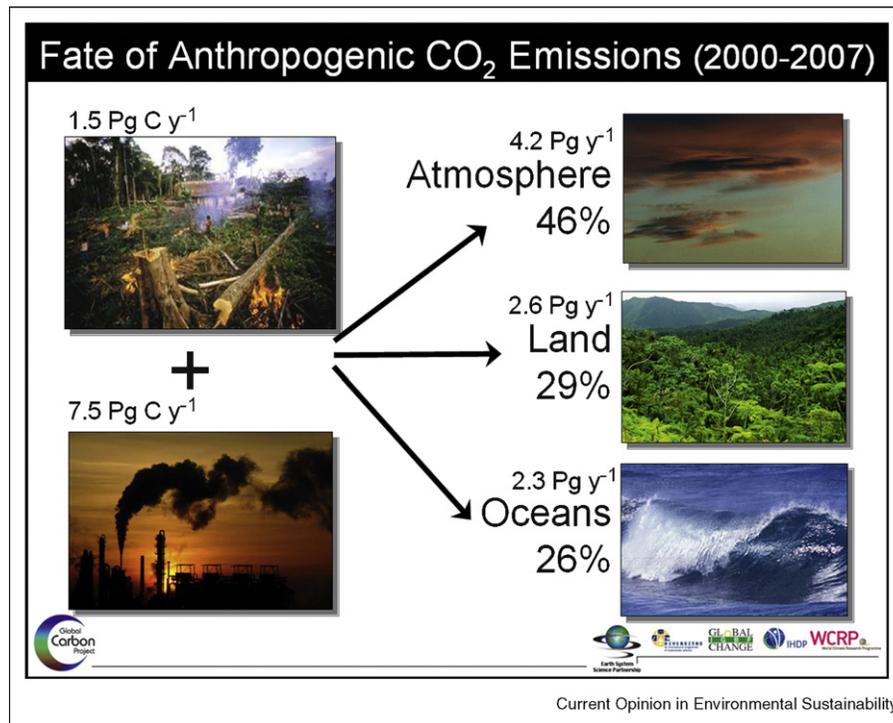
will impact further the social and economic development of Asia [12]. The GEC research programmes and their ESSP are also providing international support to assist the development of the African Network for Earth System Science, AfricanNESS [13], a network of scientists engaged in Earth system science research in Africa.

New partnerships and dialogues are forming, as the GEC programmes continue to work closely together and with other sectors of society and across all nations and cultures to meet the challenges of understanding a changing Earth. They are also providing timely and effective dissemination of scientific knowledge to decision-makers. Such science-policy dialogues are increasing the mutual understanding between our scientific community, policy-makers and others at a number of levels. However, these important activities are organised in quite an opportunistic manner and further action is required to strategise these new initiatives.

Key tasks of the ESSP

The ESSP Scientific Committee is a platform for all of the partners to come together and discuss integrative Earth system issues, which can only be addressed by collabor-

Figure 3



One of the ESSP-GCP PowerPoint slides of the 2007 Carbon Budget update [11**], which was most frequently downloaded by press, teachers and lecturers.

ation of the individual programmes, as well as a means for keeping members informed of progress within the bottom up initiatives of the programmes. At the Scientific Committee meeting in March 2009, it was determined that the ESSP has roles in the conduct of integrative science, the development of capacity and the dissemination and communication of ideas and results to various audiences, including the policy community.

The new ESSP research initiative (led by the GCP) on Bioenergy and Earth Sustainability, for example, sets a benchmark for cooperation on biofuels research. The initiative will adopt a multi-stakeholder approach, tapping into expertise of numerous GEC programmes and projects as well as intergovernmental agencies and the policy making community. The overarching goal is to identify the major opportunities and constraints for bioenergy in the context of Earth system sustainability. Although in its infancy, such an initiative provides an apt example of just the type of policy relevant research that may emerge through the ESSP. Key tasks of ESSP are described below.

Identifying and defining Earth system science challenges

Identification and framing of new societally relevant science questions is the mainstay of ESSP; although

ESSP also explores emerging issues which may have not yet become important to mainstream society. This process will include engagement with the wider community (including opinion leaders from civil society, businesses and governments) — through a two-way dialogue process, moving away from a broadcasting mode to a constructive engagement and communication mode — in the articulation of the grand science challenges. ESSP will also conduct a ‘gap analysis’ of the new initiatives to see where there can be added value and leadership from ESSP or from the individual GEC research programmes and projects.

Examples of emerging science challenges include: first, globalised land use competition, patterns, options, trade-offs, instruments for steering under (local and global) guardrails; second, the dynamics of sustainability transitions, transformations and thresholds; third, GEC and development (interconnections, trade-offs and synergies between mitigation, adaptation, sustainability, development); and four, International trade in the Earth system (e.g. embodied and virtual carbon, water, nitrogen, land and genetics, in traded goods and services; trade-offs). For example, concerning international trade in the Earth system, ESSP joint projects have already identified the importance of carbon and water embodied in food and other traded materials and this has been matched by

policy concerns about the interactions between, for example, fair trade and food miles or water management and export crops. The global flows of virtual and embodied carbon, water, nitrogen and genetic material are, however, changing rapidly with shifting trading patterns and have not been adequately monitored, modelled, projected or integrated into discussions of trade and development or the negotiations about management of climate and other aspects of the Earth system.

Another challenge is, ultimately, to develop, test, apply and release new integrated modelling approaches that combine human behaviour, environmental processes and their interactions to assess progress towards sustainability [14].

Enable research

Tapping the knowledge, expertise and networks of the GEC research community, ESSP will provide a platform for: first, information exchange amongst programmes that leads to interdisciplinary science partnerships; second, identifying scientific challenges and opportunities at interfaces of natural, social and development communities to respond to emerging needs for information from the policy and decision making communities and third, enhanced access to stakeholders and fourth enhanced access to new funding opportunities (in a constructive dialogue with funding agencies, including interaction with the International Group of Funding Agencies for Global Change Research, IGFA, <http://www.igfagcr.org/>).

Inform society

There is an urgent need to present new science insights in more accessible and informative ways to stakeholders, especially to policy-makers [15]. The challenges society faces (today and in the future) cannot be handled by one research programme or community alone. ESSP should become a knowledge and information clearing house, communicating up-to-date and timely research results in appropriate language and format to stakeholders and the user community. This requires not only effective internal and external communication amongst and between programmes and projects but also the nurturing of strategic partnerships that will enable community building for new science insights. ESSP will, therefore, execute a series of outreach activities (e.g. synthesis journal, fora, open science conferences and press releases) that will be attractive to the scientific community and society at large and increase their engagement. An example of this was ESSP's engagement in the Copenhagen Climate Change congress in March 2009 [16] and the annual science updates for UNFCCC's (United Nations Framework Convention on Climate Change) Subsidiary Body for Scientific and Technical Advice. ESSP also recognises the importance of broad interaction amongst the many scientists who contribute to its activities. As such, the partnership is committed to

hosting major international science meetings. Its first Open Science Conference — Global Environmental Change: Regional Challenges — was held in Beijing in November 2006.

Build capacity

Capacity building within the science community worldwide to undertake GEC research is an essential function to be performed by the partnership. Clearly, all the individual programmes and projects do this to some extent; however, it is important for the ESSP to consider capacity building in a comprehensive and strategic manner. Unfortunately, too often it is being regarded as something that has to be done to simply support implementation. Furthermore, the new research required to address complex Earth system problems requires focused efforts to create the new generation of Earth system scientists who will deal with regional and global problems of Earth sustainability. ESSP needs to make a much stronger argument to ensure long-term vitality of the scientific enterprise. Therefore, ESSP is currently planning a scaled-up capacity building effort to be delivered via a series of key partners but especially through START, the global change SysTEM for Analysis, Research and Training (<http://www.start.org/>). START fosters regional networks of collaborating scientists and institutions in developing countries to conduct research on regional aspects of environmental change, assess impacts and vulnerabilities to such changes and provide information to policy-makers. START also provides a wide variety of training and career development opportunities for young and mid-career scientists.

Fostering human resource capacity and building/strengthening institutions capable of creative, integrative and interdisciplinary research is a formidable challenge. Capacity building needs a comprehensive strategy towards having people and institutions in place that can enable the promotion and catalysis of high quality and highly integrated Earth system science and facilitate the application of its findings for the benefit of society and sustainability. ESSP will, therefore, develop integrative strategies for capacity building leading to:

1. Active stakeholder engagement from the beginning and throughout the development and implementation of ESSP projects.
2. Enhanced capacity to conceive, plan and conduct future Earth system science activities.
3. A lasting legacy for Earth system science leading to effective application of its findings for the benefit of society and sustainability.

Responding to societal challenges

There is now more demand for GEC science to contribute towards solutions as the stresses imposed by human activities increase on the life-support systems

of planet Earth [17]. The GEC research community faces an increasing challenge to conduct more policy and societally relevant research and to present new science insights in more accessible and informative ways to stakeholders, especially to policy-makers. Moreover, when addressing this challenge, it is important to keep in mind that successful decision support (i.e. science that improves societal outcomes), requires understanding of who the users are and of the kind of information they deem relevant and bring to bear on their decision making [18**]. Without such knowledge, information runs the risk of being 'left on the loading-dock' [19]. It is also important to stress that disciplinary science is essential and will continue to shape the very foundation of our scientific enterprise. However, greater integration across disciplines, ongoing stakeholder engagement and community-wide research are essential if we are to effectively tackle science challenges of societal relevance.

In response to this increased demand for GEC research to become more policy and societally relevant and contribute to solutions, the following new products and activities are being developed.

Knowledge products

ESSP will provide a mechanism to help promote and deliver knowledge products. As the experience with the global carbon budgets (<http://www.globalcarbonproject.org/carbonbudget>) has shown, integrative and synthetic science products (e.g. Figure 3) that are released and updated regularly, and have a direct connection with the policy process, can be very effective in influencing key policy discussions. Several other examples of such knowledge products within the different projects of ESSP and the research programmes already exist, including the GWSP digital water atlas (atlas.gwsp.org [20]; Figure 2).

Forum

ESSP will co-convene Earth system science fora with strategic partners. The first one was held at the Tällberg Forum (<http://www.tallbergfoundation.org/>), 25–28 June 2009 with the Stockholm Resilience Centre and the Tällberg Foundation on 'Making the Planetary Boundaries Relevant for Policy and Practice'. This kind of forum will serve as a vehicle for a high-level dialogue with stakeholders, including opinion leaders from civil society, business and government. The forum can also help highlight and communicate key insights from science, raise awareness and build support for interventions to support all partner GEC research programmes and their projects, and identify new key issues and areas of relevance for the Earth system science agendas of ESSP and its partners.

Synthesis journal

ESSP has facilitated the launch of an interdisciplinary, peer-reviewed journal entitled 'Current Opinion in

Environmental Sustainability' (published by Elsevier, <http://www.elsevier.com/locate/cosust>) — you are reading the first issue, which consists of papers that were invited from individual GEC researchers and from the different programmes. This journal will provide a valuable outlet for synthesising the science of the GEC research community. It should appeal to a wide audience through policy briefs, short assessments or issue summaries and it will be open access to developing country scientists and policy-makers.

Collaborative research

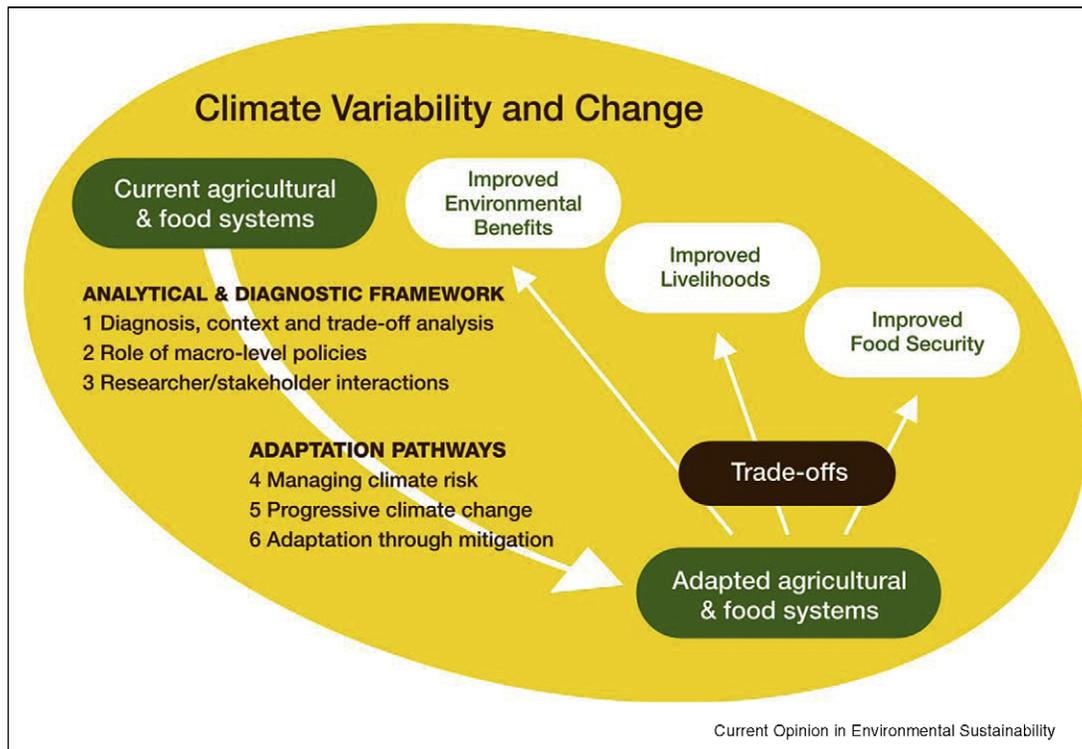
The international GEC Programme's agendas have historically been set by researchers in relative isolation of policy and resource management considerations, and on issues that are often generic in nature. Owing to the complex and region-specific nature of many GEC issues (e.g. food security), setting a research agenda that is relevant to regional and global (as opposed to generic) issues needs a highly consultative and inclusive approach. When conducted in the developing world, the links to the development agenda and particularly to the Millennium Development Goals, must be explicit. This necessarily means a further link to the development donor community (non-traditional partners in GEC research). Consequential, the GEC research agenda setting and implementation must aspire to build a number of bridges that traditional GEC science has not addressed. It must bridge natural and social and economic sciences, science and policy, and science and development. This necessitates spanning disciplines, research cultures, funding modes, and even attitudes and perceptions of what constitutes science and GEC research.

Responding to this need and to the ICSU/IGFA initiated Review [23], with the implementation of this strategy, ESSP will utilise the expertise of the GEC research community and nurture strategic partnerships in order to address GEC challenges. A good example of such a community-wide endeavour (with ESSP input to the proposal led by GECAFS is the new Challenge Program on 'Climate Change, Agriculture and Food Security' (CCAFA) [21]. This is a major collaborative endeavour between the Consultative Group on International Agricultural Research (CGIAR) and their partners, and ESSP. It is aimed at overcoming the additional threats posed by a changing climate to achieving food security, enhancing livelihoods and improving environmental management in the developing world (Figure 4). An international launch conference is anticipated in mid-2010.

The Way Forward

Coping with GEC will continue to be an enormous strategic challenge for the nations of the world, and one that humankind must meet squarely now, but will be ill equipped without suitable integrating research.

Figure 4



CGIAR Challenge Program on 'Climate Change, Agriculture and Food Security'. Research Framework and Science Themes [21].

Melting glaciers will increase flood risk; crop yields will decline in already vulnerable places like Africa; rising sea levels could leave 200 million people permanently displaced; some species groups, like vertebrates, could show a greatly increased rate of extinction; and there will be more examples of extreme weather patterns. These environmental impacts will be exacerbated further if the world's population reaches nine billion, as projected. However, the benefits of strong, early action, based on sound fundamental science, outweigh the costs [16,22].

There is a clear need for an internationally coordinated, interdisciplinary and holistic approach to GEC science from regional to global scales. ESSP is, therefore, rapidly evolving as a partnership that initiates and catalyses highly integrative studies of the Earth system including its human dimensions, to enhance capacity and to facilitate dialogue between science and society.

The ESSP plans to address emerging science challenges in concert with strategic partners. The CGIAR-ESSP Challenge Program on Climate Change, Agriculture and Food Security is a good example. Progress in this regard demands that the ESSP focus an open and continuous dialogue, foster mutual learning and deliver information in a timely manner. All this is expected to occur through an internationally coupled network in

which renowned, mid-career and young scientists can contribute regardless of location, culture or institutional background.

It has been argued that the research community has a civic responsibility to inform policy-makers and society in a timely manner of the grand science challenges we face. Nowhere is this more important than Earth system science in service to society.

References and recommended reading

Papers of particular interest, published within the period of review, has been highlighted as:

- of special interest
- of outstanding interest

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