International Group of Funding Agencies for Global Change Research
2010 Meeting
The Pavilion Conference Centre, BMW Pavilion, V & A Waterfront
Cape Town, South Africa
28-29 October 2010

IGFA

INTERNATIONAL GROUP OF
FUNDING AGENCIES FOR
GLOBAL CHANGE RESEARCH

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Agenda

Date/Time	**Topic**	**Lead**	**Location**	**Paper**
27 October				
16:00 – 18:00	**Meeting with Executive Directors of Global Change Programmes to discuss issues related to funding**	**Maria Uhle and Louis Brown**		**1. Special Session 27 October 2010 GEC_IGFA_Report_2010**
18:45 for 19:00	***Cocktail Reception Open to All Meeting Participants***		***Docks Restaurant, Gateway to Robben Island, Clocktower Section, V & A Waterfront***	**None**
28 October				
	Tea / Coffee / Juice		**Pavillion Room**	

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9:00-9:10	**Welcome Remarks**	**Dr. Gansen Pillay**	**Pavillion Room**	**None**
9:10-9:20	**Welcome Remarks**	**Tim Killeen, Alan Thorpe**		**None**
9:20-10:00	**Introduction to the Belmont Challenge, White Paper, and Collaborative Research Areas as a focus of IGFA Activities**	**Tim Killeen, Alan Thorpe, Steven Wilson**	**Pavillion Room**	**2. Belmont Challenge** **3. BC White Paper** **4. Collaborative Research Areas and Leads**
10:00-10:30	**Discussion of the ICSU Capability Study and the ICSU Visioning Process**	**Deliang Chen**	**Pavillion Room**	**5. Belmont Report** **6. Grand Challenges** **7. Summary of the Sponsors Meeting** **8. Conceptual Paper**
10:30-10:45	**Break / Refreshments**			
11:00-11:30	**Updates on Collaborative Research Areas and follow up actions by Belmont Forum Members who presented in the Belmont Forum Meeting including plans for follow up (5**			

	minutes each)			
	Water Security	**Tim Killeen**		**9. Belmont Forum Water Resources and Water Security**
	Most Vulnerable Societies	**Dawn Conway**		
	Coastal Security	**Ian Carruthers**		**10. Belmont Challenge-coasts**
	Ocean Acidification	**Steven Wilson**		
	Securing the Biodiversity Baseline	**Johannes Karte**		
	Forests and Agriculture	**Reynaldo Victoria**		
11:30-11:45	**Food Security**	**Thomas Rosswall**		**11. CCAFS Pamphlet** **12. CCAFS Report 1** **13. CCAFS Report 2** **14. Hague Conference Agriculture..** **15. MP& Proposal Document** **16. bf 2010 ccafs ltr fr rosswall**

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				17. bf 2010 ccafs note on capacity building 18. bf 2010 ccafs sugg paper
11:45-12:00	Climate Services	Ghassem Asrar		19. WCC3 Declaration 20. WCC3 Summary Report 21. WCC3 Brief Note
12:00-12:10	Summary and Next Steps	Tim Killeen		
12:10-12:30	Discussion, including opportunities for IGFA members to indicate which areas they would be interested to participate in and how and who they would like to participate, with emphasis on identification of point persons	Tim Killeen		
12:30	Lunch			
13:30-15:00	Research Programs Report on how they can and do help with follow	WCRP- Ghassem Asrar IGBP- Sybil		

	up on achieving the Belmont Challenge	**Seitzinger IHDP- Anantha Duraiappah DIVERSITAS- Anne-Helene Prieur-Richard ESSP- Martin Rice START- Hassan Virji**		
15:00-15:30	**Response and discussion in plenary**			
15:30-15:45	**Afternoon break and refreshments**			
15:45-16:15	**Regional Programs Report on how they can/do contribute to follow up on achieving the Belmont Challenge**	**Asia-Pacific Network for Global Change Research- Yukihiro Imanari Inter-American Institute for Global Change Research - Maria Uhle on behalf of**		

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		Holm Thiessen		
16:15-16:45	Response and discussion in plenary			
16:45-17:00	Close of day one and introduction of day two activities	Tim Killeen		
18:30 – 19:30	Tour of Two Oceans Aquarium	optional – participation to be confirmed with Frannie Bosman	Two Oceans Aquarium, Dock Road, V & A Waterfront	
19:30	Meeting Dinner for all participants		Predator Exhibit, Two Oceans Aquarium, Dock Road, V & A Waterfront	
29 October				
	Tea / Coffee / Juice		Pavillion Room	
9:00	Welcome	Tim Killeen		
9:05	Introduction of IGFA	Tim Killeen		22. IGFA 2009 Decisions

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	Two-year Work Plan			**and Actions** **23. IGFA Mode of Operation Document** **24. ToR Belmont Forum IGFA Council of Principals** **25. ToR Belmont Forum Working Group**
9:45-11:00	**Reaction and Discussion in Plenary**	**Tim Killeen**		
11:00 – 11:15	**Break / Refreshments**			
11:15-12:00	**Discussion of actions arising from the meeting**	**Tim Killeen**		
12:00-13:00	**Lunch**			
14:00-16:00	**Belmont Forum Working Group**	**David Allen and Gina Adams**		
16:00	**Refreshments**			

Annex I

Conference on Global Challenges for Environmental Research Funders
June 10th and 11th, 2009
Belmont Conference Center, Elkridge, Maryland, U.S.A

Conclusions and Actions

The objectives of this Conference were primarily to identify priority GCR challenges that might benefit from better international collaboration, and mechanisms to achieve this. The Conference was organized by the US NSF and the UK NERC. Participant numbers were limited in order to promote full and frank discussion. Invitees included principal officials from the most active national agencies that fund global change research, the Executive Director of ICSU and the Chair of IGFA.

The conference identified the:

- Reasons to collaborate, including the most urgent scientific and socio-political drivers;
- The primary 'Belmont Challenge' for research in order to address these drivers; and
- Actions required to take the 'Belmont Challenge' forward.

Further information on each of these outcomes is provided below.

REASONS TO COLLABORATE

Scientific drivers identified include the need to:

- Address the many issues and actions that have global impacts (e.g., carbon sequestration, rain forest functioning);
- Address the new challenges being presented to the traditional academic research agenda, through a new focus on "adaptation and mitigation", which will require;
    - global efforts to advance predictions and provide decision-support to policy-makers;
    - sharing practical knowledge, which may involve new partnerships with industry and local leaders;
    - building expertise in multidisciplinary and translational research;
- Leverage national research capabilities through access to complementary or shared expertise and facilities.

Socio-political drivers identified include the need to:

- Counter a view among policy-makers that the science is done;
    - Lay out a science agenda and call for action for international research – responding to the research questions the IPCC produces;
    - Pose research questions and costs in an appropriately broad, global and urgent way;
- Anticipate new political imperatives that will require a heightened research response;

    - Economic realities could be convincing in the near term, for example, sea-level rise/coastal inundation, with implications for infrastructure and land use;
- State more clearly the priority for helping the most vulnerable countries,
    - e.g. potential national security implications of GC driven conflict and instability;
- Engage with and influence public opinion, which may drive investments;
    - Promote dialogue on effective and acceptable solutions – to bridge the 'valley of death' from research to action;
    - Demonstrate efficiency and impact through leveraging research and shaping decision support.

THE BELMONT CHALLENGE

In order to respond to these drivers the conference identified an overarching challenge for the GCR community – to deliver knowledge to support **Human Action and Adaptation to Regional Environmental Change.**

This will require **regional and decadal prediction, advanced observing systems**, and inclusion of social sciences; and synergy of multiple stressors, including extreme events, for:
- coastal zones,
- water cycle and water resources;
- ecosystem services - food security;
- carbon cycling (including ocean acidification, deforestation, land use and soils)
- most vulnerable societies (geographic areas) – with low capacity and high societal impact

It will also require coordination mechanisms (these have a low cost but are a high priority).

MULTILATERAL COLLABORATION: SOLUTIONS

The Conference concluded that in order to address the Belmont Challenge with the required urgency, it was necessary to develop a new forum for funders and ICSU to work more closely together than ever before.

This purpose of the Forum would be to:
- Identify strategic priorities for international collaboration on GCR
- Identify mechanisms, research bodies and funding options for engagement in GCR

Limited, high-level membership (principals of the most active GCR funding bodies and those from some emerging economies, ICSU and IGFA) would be required, to promote:
- increased engagement at the early phase of strategy development, generating opportunities for co-design and co-funding of major programmes;
- frank discussions;

- strategic, targeted focus on a limited number of priorities and simplified structures;
- regular meetings, with strategic actions between meetings to sustain momentum and interest (Next meeting January 2010, London);
- an action-oriented approach, generating an integrated multinational plan for both long-term and short-term projects.

ICSU is the natural partner through which GCR funders can engage with the international science community in delivering the goals of the Belmont forum. Where research tasks need to be undertaken, the funders may ask ICSU to deliver these through its programmes.

CONCLUSIONS AND ACTIONS

The conference unanimously concluded that a continuation of the Belmont-type forum was required.

Recognising benefits of working with IGFA, and noting that IGFA is currently restructuring and establishing a new high-level consultative and policy group to guide its activities, the Conference agreed to invite IGFA, at their next meeting in October 2009, to consider structuring its 'Council of Principals' to satisfy the needs for this forum.

The Conference also asked ICSU, through their Executive Director, to conduct an analysis of international research capability to respond to the Belmont Challenge, focusing on:

- Solvability of problems;
- Infrastructure and personnel.

The Conference asked NERC to:

- Prepare a White Paper on the "Belmont Challenge" that would include a list of opportunities for funding and for major international meetings to inform;
- Host the second meeting of a Belmont-type forum, to take place in the UK in January 2010.

All participants were asked to:

- Identify opportunities for collaboration:
    - In the next six months, point to each others' aligned funding opportunities;
    - For 2010/11 – identify opportunities for co-design of support;
- Discuss the 'Belmont Challenge' and proposed White Paper with home institutions – "reality check'.

The Belmont Challenge: A Global, Environmental Research Mission for Sustainability

v. 0.8 – 13 October 2010

1. EXECUTIVE SUMMARY

In 2009, the world's main funders of environmental change research formed a new, high-level forum called the Belmont forum. Its aim is to align international resources to accelerate delivery of the environmental science-derived knowledge and capabilities that society needs to address environmental change.

This paper sets out the Belmont Forum's priorities for this knowledge and capabilities, and the underpinning research and organisational challenges needed to deliver them. It will form the basis for funders to engage in dialogue over future months with stakeholders from research, government, business and civil society, with the objective of mobilising new partnerships and their collective resources to deliver a global environmental research mission for sustainability.

We seek to add value to strategies that are currently evolving from the environmental change research community. As public sector funders, we offer perspectives from the nexus of research and government, where we are responsible for prioritising investment of public money towards research approaches that can deliver the greatest welfare and economic benefits to society. It is clear to us that: (i) the priority research challenges should be those that can deliver the knowledge society needs, and (ii) stakeholders from government, business and civil society must play a full role directing, governing, using and supporting this research.

We consider that:

In recent decades Earth System science has provided society with a valuable, basic understanding of the environment and human society as interconnected systems, how humans are changing the global environment, and how these changes may affect human well-being.

To enable society to address environmental change in the 21st century, this knowledge of the Earth System must now be built on, to provide information on impacts, vulnerabilities and risks of environmental change and adaptation and mitigation strategies. This knowledge must be provided at decadal and regional scales, at which decisions are made. The research and knowledge will create unprecedented opportunities for equitable economic and social development. Funders have defined the 'Belmont Challenge' to describe this need:

> ***To deliver knowledge needed for action to avoid and adapt to deleterious environmental change including extreme hazardous events.***
>
> *This requires:*
> - *regional and decadal analysis and prediction,*
> - *advanced observing systems,*

- *integration with social sciences,*
- *effective coordination mechanisms,*

With priority foci being:

- *Coastal Vulnerability*
- *Freshwater Security*
- *Ecosystem Services*
- *Carbon Budgets*
- *Most vulnerable societies*

Priority knowledge and capabilities that the Belmont Challenge must deliver for society over the next decade and beyond include:

- Predictions of risks, impacts and vulnerabilities,
- Information on the state of the environment,
- Enhanced environmental information service provision to users.

These capabilities are highly interdependent and need to be delivered in an integrated way. We propose an Earth System Analysis and Prediction System (ESAPS) as an integrating framework around which to organise the research and knowledge. An ESAPS would: overcome critical limitations for development of predictive models by promoting assimilation of improved environmental data; support evidence-based decision-making by linking interconnected elements of the policy cycle; and build on the concept of Climate Services by adding information about multiple environmental change stressors, to provide 'Environmental Services.'

The intellectual and organisational challenges involved in delivering an ESAPS and meeting the Belmont Challenge require a profound change to the way we support and undertake global environmental change research. In particular, there are needs for: overarching strategic governance to establish key priorities among competing demands and promote cooperation; a greater voice of users in defining and governing the research priorities; a step-change increase in collaboration across disciplines, which will require framing environmental change challenges in ways that engage groups other than environmental sciences, and across regions, especially to build capacity in developing countries; and improved mechanisms for major transnational funding, that overcome current constraints to cross-border support while adhering to national requirements and statutes.

Recently, a number of international initiatives by intergovernmental and research communities, in addition to the Belmont Forum, have started to consider and stimulate organisational change to address challenges included above. We propose that these initiatives are drawn together, with stakeholders from business and civil society, into a high-level joint strategic task force. This task force would, over the next 1-2 years, develop a comprehensive strategic roadmap for supporting and delivering an integrated research mission for sustainability. It would refine and prioritise the research challenges, secure the necessary political and financial support, and build the necessary links with decision-making systems to facilitate the update of research outputs by users.

2. INTRODUCTION

This White Paper sets out the perspective of many of the world's major environmental research funding agencies on the 'grand challenges' for global change research that need to be delivered over the next 10-20 years, to support sustainability. These perspectives will form the basis for funders to collectively engage in dialogue over future months, with research providers, coordinated through ICSU and ISSC, and with the primary users of research from government, business and civil society. The objective is to mobilise partnerships and their collective resources to support and deliver a coordinated global environmental research mission for sustainability.

The paper considers:

- The critical environmental and social-science derived knowledge and capabilities that society needs to respond appropriately to the threats and opportunities precipitated by environmental change in the 21st century,
- The pivotal research challenges that need be met to provide this knowledge and capability. The focus is explicitly on interventions that require global-scale international cooperation, are solutions-focused, and integrate observations, prediction and knowledge platforms,
- The essential need for a new strategic and integrated partnership approach, in order to mobilise the resources and build the capacity needed,
- The key requirements of a Roadmap for delivering this transformative international research agenda, focusing on partnerships between funders, providers and users of research, coupled with appropriate prioritisation.

3. BACKGROUND

Developing an Understanding of the Earth System and Global Environmental Change

In recent decades Earth System science has provided society with a basic understanding of the environment and human society as interconnected systems. It has started to generate understanding of how human actions are changing the global environment and predictions of how these changes may affect future human well-being. We know that humankind is pushing important environmental variables on which we depend (climate, freshwater, biodiversity, elemental cycles) outside the stable boundaries that they have exhibited over the last 10,000 years. This period, the 'holocene' is the one during which human society has evolved and prospered[1]. There is no doubt that our current path is unsustainable. Evidence is emerging that the rate and magnitude of anthropogenic environmental change is moving towards states beyond our ability to control or adapt to it [2]. The Global Environmental Change programmes (IGBP, WCRP; IHDP, DIVERSITAS and their partnership programme ESSP[1]) coordinated under the auspices of ICSU, and international observational programmes (such as GCOS, GEO/GEOSS) have played an important role in directing, synthesizing and communicating research to promote this improved understanding of global environmental change.

[1] Spell out acronyms

Providing Science-Based Solutions

The information that society now needs, in order to respond to the challenges of global environmental change, must build on this basic and global-scale understanding to provide science-based solutions for societal action. Society needs critical information about interconnected environmental and societal risks and how to manage them, including how to protect life and property, make decisions about trade-offs between different enviro-societal management options, and transition to sustainable economies. This will require science-based knowledge about the impacts of global environmental change at much higher resolutions than provided to date – specifically at the regional and decadal scales at which decision-makers operate. The information will need to be aligned with influential societal decision-making systems.

By providing the foresight and insight to enable innovative technical and societal solutions to environmental change, research will create unprecedented opportunities for equitable economic and social development. These will include:

- Enabling effective transitions to low-carbon, resource-efficient economies, through assessing whole-system impacts and trade-offs for innovation options in sectors such as energy, agriculture, water and waste,
- Providing an evidence base for development, auditing and regulation of new markets for trading ecosystem services, such as carbon sequestration, nitrogen fixation, water purification, etc.,
- Monitoring and forecasting to protect property and infrastructure, reducing average insured losses and providing confidence for investment,
- Improving health and well-being through reduced vulnerability to natural hazards and pollution, and
- Lifting people out of poverty through supporting innovative sustainable development pathways towards Millennium Development Goals

Providing this knowledge, predictions and decision-support tools, with the required urgency, is an enormous intellectual and technical challenge. Understanding the interconnectedness of the 'Earth System' across its physical-chemical-biological- -societal dimensions and across spatial and temporal scales, and leveraging this understanding to predict changes and inform behaviours and decisions, will require interdisciplinary conceptual frameworks of enormous complexity. Understanding what environmental information is most crucial to know, and what measurements, technologies, and models are needed for this, is a significant challenge in its own right. Delivering the this data collection and provision, modelling and stakeholder engagement will require a step-change in technical capabilities (particularly in high-performance computing, data management, sensor technologies, and interactive communication tools). These are 'Grand Challenges' and require new ways of prioritising, funding and doing research that can mobilise and coordinate the resources of all stakeholders in a decade-long mission for sustainability.

International research communities have recently described their priorities for 'grand challenge' research for sustainability. For example:

- “Grand Challenges in Global Sustainability Research: A Systems Approach to Research Priorities for the Decade”[2] developed by ICSU as part of its ongoing visioning process,
- “Regional Environmental Change: Human Action and Adaptation – What does it take to meet the Belmont Challenge”[3] – a report of an ICSU Panel commissioned by the Belmont Forum of Environmental Change Funding Agencies,
- Developing a common strategy for integrative global environmental change research and outreach: the Earth System Science Partnership[4] – a strategy paper of the ESSP,
- A Safe operating space for humanity[1] – coordinated by the Stockholm Resilience Centre,
- WMO Third World Climate Conference – Declaration to Establish a Global Framework for Climate Services (September 2009).
- Nobre et al. – An Earth System Prediction Initiative for the 21st Century[5], and
- [WMO WCC3 Statement on Global Framework for Climate Services – GA to add proper title]

There is considerable alignment among these analyses and visions. In particular around the need for:

- Improved forecasts of regional and decadal scale changes that fully take into account coupled natural-human systems – requiring a suite of integrated Earth System Models,
- Observations of the Earth system that can validate models, provide early warning of change and support decision making - requiring advanced observing systems that integrate environmental and social data, quantitative and qualitative data, and historical and contemporary data and are at a high-enough resolution to detect systematic change and capture extreme events,
- Knowledge of ‘tipping points’ (critical thresholds at which non-linear environmental change will occur that will disrupt wellbeing of society), our proximity and vulnerability to them, and strategies for avoiding, adapting and enhancing our resilience to them – requiring integration of environmental and complexity science, and of ‘impact’ and ‘response’ research,
- Knowledge of technical and social innovations that can overcome barriers to sustainability, likely to include options for international trade in the Earth System – requiring highly integrative and synthetic science, and comparative assessments of whole-system and whole-life-cycle environmental impacts and trade-offs for different options, and
- Knowledge platforms – two-way information and communication tools that support the needs of sectors such as agriculture, energy, insurance, health, transport etc for information on forecasts, impacts, vulnerability and adaptation – will require a step-change in science-society bridging activities and capabilities, including mechanisms to enable science to be directed in response to user-identified needs.
- Co-design of research agendas among stakeholders - connecting scientific, economic and social development agendas in directing and benefiting from research.

The existing Global Environmental Change Programmes, each undertake research relating to these needs, and frequently do so in partnership with users, especially from intergovernmental bodies. However, it is recognised by research providers and funders alike that the impact of the programmes may be limited by their current organisation, which has evolved in an opportunistic and fragmented way. Intervention to promote strategic overarching direction and prioritisation, and integration across structural borders, in which all key stakeholder sectors are engaged, is needed, if we are to succeed in securing support for and delivering the research mission for sustainability.

4. THE FUNDERS' PERSPECTIVE: THE 'BELMONT CHALLENGE'

Funders of environmental research are part of the equation for realising a research mission for sustainability and are keen to see the enhanced level of coordination needed. In July 2009, the world's major funders of environmental change research, and ICSU, met at Belmont House, Maryland USA, to consider how best to align financial and human capital towards delivering the environmental science knowledge base that society will need in the 21st century. (This group has since been called the 'Belmont Forum' and it operates as the Council of Principals for the broader International Group of Funding Agencies for Global Environmental Change Research (IGFA)).

As funders, we do not seek to introduce an additional or alternative vision into the mix of strategies emerging from the global environmental change research community. We seek to add value to them by contributing a funders' perspective on how emergent 'grand challenge' research might be prioritised and organised, in order to maximise the impact of, and potential for, sustainable, international support of the magnitude required. We offer this perspective as agencies that, operating at the nexus of research and government, are responsible for prioritising investment of public money towards research approaches that can deliver the greatest welfare and economic benefits to society. It is clear to us that: (i) the priority research challenges should be those that can deliver the knowledge society needs, and (ii) stakeholders from government (including public sector funding agencies), business and civil society must have a central role in the joint, strategic governance of the research, playing a full role directing, governing, using and supporting it. In other words, the international global change research community must 'seal' the contract with society, first proposed by Jane Lubchenco[6] in 1998.

As a result of the July 2009 meeting, funding agencies, defined 'The Belmont Challenge' around which, in our view, international collaborative research should be focused. During 2010 we further articulated and prioritised the sub-challenges within the Belmont Challenge. The Belmont Challenge takes account of the strategic visions set out by international research communities described above, as well as our organisations' own strategic priorities, as informed by our research communities, our governments and our stakeholders in business and civil society. Our priorities are in broad agreement with the analyses of the world's major scientific programmes and councils.

The Belmont Challenge is:

To deliver knowledge needed for action to avoid and adapt to deleterious environmental change including extreme hazardous events.

This requires:
- *regional and decadal analysis and prediction*
- *advanced observing systems,*
- *integration with social sciences,*
- *effective coordination mechanisms,*

With priority foci being:
- *Coastal Vulnerability*
- *Freshwater Security*
- *Ecosystem Services*
- *Carbon Budgets*
- *Most vulnerable societies*

Critical Interventions

We suggest below some priority knowledge and capabilities that the Belmont Challenge must provide society, and some of the pivotal research challenges and capacity-building needed to get us there.

The priorities for knowledge and capabilities are organised into 3 areas:
(a) Predictions of risks, impacts and vulnerabilities,
(b) Information on the state of the environment,
(c) Enhanced environmental information service provision to users.

The capabilities are highly interdependent. Scientifically, our technical ability to develop improved predictive modelling tools will depend on assimilation of improved data in the state of the environment. Furthermore, society's decision-making needs require them to be interlinked, since monitoring, analysis and evidence-based information are interconnected components of the policy-cycle. It is therefore essential that these capabilities are developed in an integrated way. In priority (d) we propose the development of an Earth System Analysis and Prediction System (ESAPS) as an *initial* example of a potential mechanism to integrate and coherently organise global change research outcomes to support decision-makers in dealing with critical issues in global change such as adaptation, mitigation or integration of climate services.

The priorities listed in (a) – (d) below are not exhaustive. In particular they lack social science dimensions. We also lack information on the extent to which the priorities can be met through improved coordination of existing capability, or where investment in new capability is required. Further development and prioritisation should take place as part of the Roadmap described in section (5) below.

a) <u>Predictions of risks, impacts and vulnerabilities</u>: To provide foresight about changes in the Earth System at Regional and Decadal Scales, which takes

full account of societal interactions and focus on changes that may cause abrupt and potentially irreversible and disastrous changes

Priorities will include developing predictive capabilities for:

i. The likelihood and severity of extreme hydro-meteorological events and their impacts on human socio-economic systems in a given geographical region, from seasons to decades, under different GHG emission and land-use scenarios,

ii. Likelihood of biodiversity loss that will compromise provision of essential ecosystem services for a given terrestrial or marine region, under given climate and management scenarios, and

iii. Predictions of the environmental and health impact of changes to other biogeochemical cycles (e.g. nitrogen, phosphorous) or to increased loadings of toxic pollutants

Underpinning Research Challenges:

We agree with the consensus among the international science communities, about the need for convergence around limited number of Earth System models, which can then be developed into a hierarchy of models with regional capability. The models must have the ability to analyse and predict change to the Earth system that includes representation of coupled, physical, chemical, biological, social and economic processes. Development of, and outputs from, these models should be linked to decision-making systems.

The modelling studies should focus on the probability of occurrence of future extreme events, the impacts of these on human societies, and consequences (including costs) of different adaptation and mitigation strategies. This will require understanding of non-linear dynamics and thresholds beyond which systems tip into alternate states. Predictions of impacts and risks that compare and integrate 'bottom-up' approaches (i.e. critical thresholds) and 'top-down' approaches (e.g. downscaling) will be important for providing maximum insight and benefit to users.

b) Information on the state of the environment: to verify the accuracy of predictions, assess proximity to disruptive change and monitor the effectiveness of management strategies.

Priorities will include observing systems that provide:

i. Data and knowledge to improve, verify and refine model predictions at regional and decadal scales,

ii. Data and knowledge to assess proximity to disruptive tipping points in order to identify vulnerable regions/societies, provide early warning of disruptive change (e.g. Extreme hydro-meteorological events, disruption of ecosystem services, etc.), and inform avoidance/adaptation strategies, and

iii. Monitoring of stocks and fluxes of key environmental change variables (e.g. carbon, nitrogen, water, deforestation) to support markets and regulation.

Underpinning Research Challenges

There is a need for linked sensors, data preservation and information systems that are prioritised on environmental and social variables that characterise dynamics and vulnerabilities of regions and systems.

Data/information systems must be accessible, with a range of data products and visualisation tools for non-specialists and linked with decision-making systems.

In order to maximise efficiency of existing capability, there is a need to improve coordination between existing observational and data systems, and between academic and operational systems. There are currently some major international programmes aimed at improving effectiveness and coordination of global and regional monitoring systems (e.g. GEOSS; ICSU World Data Systems, WMO) that will be important partners.

c) Enhanced environmental information service provision to users through knowledge platforms: Delivering applied knowledge to support innovative adaptation and mitigation solutions, based on the observations and predictive knowledge outlined in (a) and (b)

These must enable:

i. Interaction with end users to identify what predictive and observational capabilities will bring most effective knowledge for adaptation and mitigation solutions,

ii. Products developed on a regular schedule, tailored to user needs,

iii. Identification of strategies needed to reduce vulnerability to change (mitigation or adaptation), and

iv. Comparative analyses (costs and benefits) of different mitigation and adaptation strategies, based on whole-system, whole-lifecycle impacts, vulnerability and risks. Include assessments of the trade-offs and strategies to mange the tradeoffs.

ICSU[2] has identified some priority needs for information on strategies and tradeoffs including: How can global energy security be provided entirely by sources that are renewable and have neutral impacts on other aspects of global sustainability; How can competing demands for scarce land and water be met over the next half-century – while dramatically reducing land use GHG emissions, protecting biodiversity and maintaining or enhancing other ecosystem services; How can ecosystem services meet the needs for improving the lives of the world’s poorest peoples and those of developing regions (such as safe drinking water and waste disposal, food security, and increased energy use) within a framework of global sustainability? What are the potentials and risks of geo-engineering strategies to address climate change?

Underpinning Research Challenges

New information systems and tools to support communication and participatory research approaches between research providers and users are needed. These platforms will need to provide information and services beyond those traditionally provided by national meteorological and environmental services – e.g. to sectors including agriculture, insurance, investment, health, transport, commerce and manufacturing. The systems will also need to transcend national perspectives and serve global users.

Comparative analysis of different approaches towards risk reduction will require development of risk models, and multi-disciplinary quantitative analysis of their outputs. It will be important to identify any potential unintended consequences of changes. The risk models will need to be able to integrate quantitative and qualitative information.

(d) Development of Integration Mechanisms

There would be enormous benefits from integrating the research and knowledge products outlined in (a) – (c) to provide stakeholders and decision makers with a holistic decision-support system for critical issues facing global change mitigation and adaptation, including, but not limited to Earth systems analysis and prediction Integration of observations, and analysis would overcome critical limitations to model development for environmental change, on global, regional and eventually local scales . Integration of observations, modelling and knowledge platforms would ensure connectivity between key components of the policy-cycle, on which evidence-based decision-making depends. It would also build on the concept of Climate Services, adding information about multiple environmental change stressors, to provide 'Environmental Services'.

An example of such a mechanism is an Earth System Analysis and Prediction System (ESAPS). The ESAPS would seamlessly align and integrate distributed environmental change research capability around the world. It would focus on research, observation systems and knowledge that require global cooperation. Application of this information for addressing specific national, regional and local issues would be undertaken by national, regional or local organisations.

Key elements of the ESAPS would include:

- As comprehensive a description of as many components of the Earth System as possible, subject to the constraint of the computational resources available
- A fully-coupled data assimilation system, allowing observations of all components of the Earth System to be brought into the analysis-model system

- Credible re-analysis of the last 50 years, as a vital test of the system
- Prediction capability with clearly defined societal driver scenarios used for the unknowable (typically human behaviour) elements.

Capacity Building

Delivering an Earth System Analysis and Prediction System to address the Belmont Challenge over the next decade and beyond requires a comprehensive strategy to mobilise, align and strengthen the human, institutional and financial resources of funders, providers and users of environmental research. Priority elements of this strategy should include;

- Governance – An authoritative, international, multi-sectoral partnership, with effective representation from the major stakeholder groups will be critical for establishing clear priorities among competing demands, promoting cooperation among key players, and championing uptake of outputs. This relationship must go beyond governments to include business and civil society,

- Collaborative Research – integrating the full range of sciences and humanities and cross-regional to global scales. This will require framing environmental change issues in ways that encourage and enable participation of groups other than environmental scientists, especially social scientists. Networking existing centres of excellence across regions and disciplines will be important. Such a network would build a focus on interdisciplinary Earth System science, while incorporating regional initiatives. It would provide access to state-of-the-art facilities and training to scientists around the world,

- Building Capacity in Developing Countries – in order to assess regional aspects of global environmental change, impacts and vulnerabilities, and provide information to public and private sector decision-makers there is an enormous need for capacity building in developing countries. Regional networks of partnerships between scientists and institutions from developed and developing countries to conduct research are important and could facilitated through the network of centres of excellence, described above

- Next Generation Sustainability scholars - a major and transformative effort will be required to train graduate, doctoral and post-doctoral researchers with the interdisciplinary, cross-sectoral skills needed to address context-specific problems of sustainability

- Enhanced mechanisms for major transnational funding – a suite of collaborative tools is needed that overcome current constraints to transnational funding while adhering to national requirements and statutes. These should span the spectrum of cooperation, from alignment and sharing of national programmes and capabilities to co-design and co-funding of joint programmes and capabilities.

The organisational changes needed to develop this capability represent a profound change to the way we do environmental science today. However, a number of initiatives, linked to the strategic visioning activities described above, are starting to consider and stimulate appropriate organisational change. These include: Strategic alignment of funding agencies through establishment of the Belmont Forum; The Global Environmental Change Programme's analysis of new institutional frameworks required for global sustainability research, led by ICSU; and the WMO High Level Task Force that is developing an Implementation Plan for a Global Framework for Climate Services.

5. ROADMAP

The Belmont Forum proposes that a high-level, **joint strategic task force**, with representation from across the major stakeholder groups (research providers, research funders, government, business and civil society) is established as an over-arching governance mechanism to drive forwards the integrated, global research mission for sustainability set out under the Belmont Challenge and ESAPS. Such a task-force is consistent with a proposal discussed by global environmental change programmes and funders as part of the ICSU Visioning process in June 2010. We consider it essential that only one such group is established, and that it is developed jointly through funders and the Global Environmental Change community coordinated through ICSU and ISSC, and in partnership with other stakeholders.

Over the next 1-2 years, this task force would develop a comprehensive, strategic **Roadmap** for supporting and delivering the 'grand challenge' research needed over the next 10-20 years. The strategic task force would be responsible for: establishing the research priorities; securing political and financial support; promoting the integration of existing programme structures into more streamlined systems; commissioning ICSU and ISSC, the Global Environmental Change Programmes, International Observational Systems, and other appropriate providers to deliver the research; and building the necessary linkages with decision-making systems to facilitate uptake of the research outputs by users.

The Roadmap should:

(a) **Refine and prioritise** the needs for environmental-science derived knowledge and capability set out above and in the visions and strategies of the international scientific organisations and other stakeholders from government, business and civil society. A priority will be more strongly engaging social science and user voices in determining these priorities.

It should agree the **outcomes** required (knowledge, capability and services needed by society and corresponding underpinning research challenges) and a **strategy** (key players (funders, providers, users), timetable and budget) for delivering them. The outcomes and strategy should be clearly **prioritised.** The prioritisation should have at its core the critical research and integration needs and mechanisms to provide environmental information services to governments, business and society at large (such as through an ESAPS). It should also reflect the urgency with which the information is needed, and the tractability of the research providing that information. This prioritisation should include identification of 'quick wins' where there is significant existing capability to deliver an outcome.

(b) Ensure that wherever possible, implementation focuses on **increasing the effectiveness of existing capability, through improved prioritisation and coordination.**.

Specify which outcomes of the roadmap can be delivered by more focused and coordinated use of existing research national and international research programmes, infrastructure and training. Set out a strategy for organising the existing capability and delivering the resulting outcomes, to include:

- coordination and integration of existing observations, datasets, programmes, training and knowledge exchange platforms, and
- reallocation of resources from capability that is not a priority, to enhance capability that is

(c) Identify which outcomes require **investment in new capabilities** (i.e. cannot be delivered by more efficient use of existing capability). Set out a strategy for delivering the new investments and the resulting outcomes.

Over the next few months, the Belmont Forum, in partnership with ICSU and ISSC, will discuss with stakeholders from research, government, business and civil society, our proposal for a Joint Strategic Task Force to develop a Roadmap for the global environmental science mission set out in the Belmont Challenge and ESAPS. The objective of these discussions will be to identify how the funders' research agenda may be best aligned and taken forward with similar emerging high-level strategies of our stakeholders.

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	6(a) Social Science Fora	**6(b) Capability Study**	**6 (c) Climate Services**	**6(d) Coastal Zone**	**6(e) Water Security**	**6(f) Food Security**	**6(g) Biod. Baseline**	**6(i) Land use trade-offs**	**6(j) Ocean Acid.**	**6(k) Forests and Ag.**	**6(l) Most Vuln. Societies**
Ian Carruthers (Anthony Swirepik)				LEAD	✓		✓	✓	✓	✓	✓
Deliang Chen		LEAD		✓			✓				
Yiyu Chen (Chai Yucheng) (ZHANG, Chao-lin)				✓	✓						
Dawn Conway (Tim Aston)				✓							
Carlos Henrique de Brito Cruz				✓			✓	✓		LEAD	
Heide Hackmann	LEAD			✓							
Albert van Jaarsveld (Frannie Bosman)				✓	✓	LEAD	✓	✓	✓	✓	✓
Johannes Karte				✓			LEAD	✓		✓	
Tim Killeen (David Allen)			LEAD	✓	LEAD	✓	✓	✓	✓	✓	✓
Wilfried Kraus				✓		✓		✓		✓	
Margaret MacCuaig-Johnston (andre.isabelle@nserc.ca)				✓						✓	LEAD
Patrick Monfray				✓		✓	✓		✓		
Manuela Soares (Nikolaus Cristofroides)				✓		✓	✓	✓		✓	✓
Alan Thorpe (Gina Adams)				✓	✓	✓	✓	LEAD	LEAD	✓	✓

6 (h) Human Health - deferred to next meeting
6 (m) Bio and Renewable Energy, Geoengineering - carried forwards to next meeting

Regional Environmental Change: Human Action and Adaptation

What does it take to meet the Belmont Challenge?

ICSU
International Council for Science

ICSU

Founded in 1931, the International Council for Science (ICSU) is a non-governmental organization representing a global membership that includes both national scientific bodies (121 National Members representing 141 countries) and International Scientific Unions (30 Members). The ICSU 'family' also includes more than 20 Interdisciplinary Bodies—international scientific networks established to address specific areas of investigation. Through this international network, ICSU coordinates interdisciplinary research to address major issues of relevance to both science and society. In addition, the Council actively advocates for freedom in the conduct of science, promotes equitable access to scientific data and information, and facilitates science education and capacity building. [www.icsu.org]

Suggested citation: ICSU (2010). Regional Environmental Change: Human Action and Adaptation. International Council for Science, Paris

ISBN: 978-0-930357-82-5

Regional Environmental Change: Human Action and Adaptation

What does it take to meet the Belmont Challenge?

Preliminary report of an ad hoc ICSU panel

August 2010

Preface

In late 2009 the Belmont Forum, a group of major funders of international global change research, invited the International Council for Science (ICSU) to conduct an analysis of the international research capability required to respond to the challenge of delivering knowledge to support human action and adaptation to regional environmental change. This challenge was named the Belmont Challenge and requires regional and decadal prediction, advanced observing systems and the integration of the social sciences.

To address this task, ICSU set up a panel consisting of 15 international experts with Guy Brasseur as the chair (Annex 1). While the panel members served in their personal capacity, the report was able to benefit from, and build upon, the collective wisdom of a large community with which they interact. The analysis draws on the existing synthesis and assessment products of the broader scientific community, the experiences and strategic plans of the global change programmes[1] and other related international and national activities, and many peer-reviewed papers. This report summarizes the panel's findings.

The report has undergone extensive peer review. Inputs were sought from relevant ICSU bodies and other organizations. Nevertheless, the scale of the task and the limited time available did not permit a comprehensive analysis of all issues; consequently, the report should be regarded as a preliminary analysis. Indeed, one of the outcomes of the analysis is the realization that the details of the Belmont Challenge itself need to be better specified, and further studies on a number of important areas are needed.

Initially, the starting point and thus the focus of the Belmont Challenge was: 'to deliver knowledge to support Human Action and Adaptation to Regional Environmental Change'. It was recognized that decadal prediction would be an essential first step in this process, but after some consultation, particularly with external reviewers and the Belmont Forum, it was decided to expand the analysis to include mitigation. To some extent this is reflected in the structure of the report and the fact that coverage of areas is somewhat uneven.

While this report was being drafted by ICSU, parallel work was being conducted by the Belmont Forum to detail the Belmont Challenge, in the form of a white paper. Unfortunately, the timing was such that the panel could not take full account of this work. Despite these limitations, we nevertheless hope that the report will be a useful starting point for addressing the Belmont Challenge, since it represents an important component of a complete Earth system research agenda.

In 2008 ICSU initiated an Earth System visioning exercise that has defined five grand challenges for global sustainability research, with concrete scientific questions under each of the challenges. Some of the visioning outcomes cover elements set out in the Belmont Challenge. Although this analysis and the visioning process are two independently designed processes, the overlap in the priorities identified only serves to underline their importance.

Partly due to the overlap, there has been some confusion, within the research community, about the two parallel processes. While the visioning process was mandated by the ICSU General Assembly in 2008 to outline options for an overall framework for global environmental change research, the present report is an analysis requested by the funders and should not be regarded as an implementation plan for the visioning process, although the discussions and suggestions of the analysis may provide useful inputs to the ongoing visioning process.

[1] DIVERSITAS, an International Programme of Biodiversity Science; International Geosphere-Biosphere Programme (IGBP); International Human Dimensions Programme on Global Environmental Change (IHDP); World Climate Research Programme (WCRP); and Earth System Science Partnership (ESSP).

This report is the culmination of contributions from many organizations and individuals. In addition to the panel members and the contributors listed in Annex 1, many others have played an important role. On behalf of ICSU, I would like to express very sincere thanks to the dozens of reviewers whose advice and recommendations have served to significantly improve the report. A special thank you goes to Guy Brasseur, and to Mel Shapiro who assisted the chair of the panel in a most efficient and effective way. NSF provided financial support to the project. Colleagues from the Belmont Forum also provided useful information about the articulation of the Belmont Challenge and feedback to earlier versions of the report.

Deliang Chen
Executive Director
ICSU

Contents

Executive Summary and Recommendations

In June 2009, the US National Science Foundation (NSF) and the UK Natural Environment Research Council (NERC) led a meeting in Belmont, Washington DC, attended by representatives of several of the world's major global change research funding agencies and the International Council for Science (ICSU). These agencies, supporting basic and applied research in Earth system science, identified a challenge for the international scientific community to *develop and deliver knowledge in support of national and international government action to mitigate and adapt to global and regional environmental change with an emphasis on regional hazards.* This challenge is hereafter referred to as the *Belmont Challenge*. In response, a panel was assembled by ICSU. It was tasked to assess the willingness, readiness and capacity of the international research community to respond to the Challenge and to address issues related to the integration of weather, climate, ecosystem, energy, health, agriculture, engineering and social science research, emphasizing near-term (year-decade), as well as medium-term (20 years) options, challenges, and approaches to the needed level of international activity. This requires a dialogue between stakeholders (political, economic and social actors, either as individuals, groups or organizations), and natural and social scientists.

The environmental problems facing today's society cannot be overcome by a single nation or a single scientific discipline. Responding to these challenges demands highly coordinated and collaborative research and service agendas. The panel proposes a research agenda to provide the scientifically based information needed by local, national and international decision makers, as they take actions for the benefit of society and environmental sustainability. This agenda will mobilize the full spectrum of scientific disciplines. Reducing vulnerability and increasing resilience to environmental stress is a unifying goal of the diverse communities involved in these issues.

The panel highlights the need for the development and implementation of:

- Integrated tools for analysis, prediction and projection in support of the capability of environmental management to identify and respond to hazards, risks and vulnerability, and to develop mitigation and adaptation strategies. A major challenge is to develop integrated Earth system analysis and prediction systems, including the characterization of regional vulnerability and risks.
- More effective use of physical and societal observations to improve global-to-regional environmental analysis and prediction.
- Information/communication tools and facilities that provide authoritative and easily accessible information to policy makers and decision makers.
- Capacity-building strategies in both developing and developed countries, as well as scientific partnerships between institutions from different geographic regions of the world.

The panel recognizes the urgent need to:

- **Coordinate efforts and enhance the support** required to address the needs of a sustainable environment and the needs of society. The challenge is to integrate environmental and developmental issues that have often been addressed independently in past decades.
- **Facilitate the dialogue between scientists, decision makers and the general public** to support decisions and actions at the forefront of society's needs.
- **Encourage natural and social scientists to work together** to ensure that environmental observations, analyses, predictions and services most effectively meet the needs of society.
- **Maintain and expand access to, and use of, the current global observing and monitoring systems** through coordinated databases and develop assimilation procedures to achieve the maximum benefit.

- **Respond to society's increasing demand for detailed information** at the regional and local scales. This requires sector-relevant information that includes observations, analyses, high-resolution projections/ predictions at timescales from days to decades.

The panel established the following priorities to address the Belmont Challenge:

- **Develop Earth system knowledge:** Building on past successes, mobilize existing research teams and networks to develop and deliver the knowledge required to address pressing global to local environmental and societal issues, with the support of funding agencies and national and international programmes.
- **Facilitate the communication of knowledge to decision makers:** Identify the objectives and means for effective translation and communication of scientific knowledge for targeted sectors and regions in order to realize the intended benefits from the application of such knowledge.
- **Nurture the next generation of experts:** Invest in training scientists and associated staff through fellowships and research grants, emphazing scientific challenges at the interface of natural and human systems.

The panel recommends the following actions by the funding agencies:

1. **Establish an international research and educational network for Earth system science.**
2. **Promote the development of the human capital** required to address the Belmont Challenge.
3. **Establish multi-national interdisciplinary and transdisciplinary teams** that promote a dialogue with decision makers to identify the key environmental and societal issues that regions are facing.
4. **Encourage diverse approaches** for the analysis of multi-stressors, responses and feedback processes affecting the physical, chemical, biological and social systems in selected regions particularly prone to human perturbations and environmental change.
5. **Develop and coordinate advanced experimental, observational, and computational facilities** that address the Belmont Challenge and provide support for the operational and maintenance costs of these facilities.
6. **Develop integrated Earth system models** with global and regional capability that provide predictions and projections of the evolution of the Earth system, including weather, climate and other environmental changes, the occurrence of natural and human-induced extreme events, as well as the impacts of these changes on ecosystems and human society.
7. **Conduct a study focusing on issues associated with the integration of natural and social sciences.**
8. **Address issues related to the vulnerability and adaptability of human societies** to environmental change and risks affecting vulnerable regions, as well as the economic and environmental impacts of potential mitigation and adaptation strategies.
9. **Initiate partnerships between nations** to draw on their collective scientific and societal expertise; support the special research and infrastructure needs of developing countries.

1. Introduction

There is emerging interest within national academic research funding agencies to coordinate their support for international and interdisciplinary Earth system research. In June 2009, the US NSF and the UK NERC led a meeting of principals of several of the world's major global change research funding agencies and ICSU, in Belmont, Washington DC. Participants at the Belmont meeting agreed on the need for an improved forum for dialogue between research funding agencies and the scientific community represented by ICSU, and for a coordinated process for early-phase engagement on global environmental change research strategies and priorities. As a result, a new high-level forum, called the Belmont Forum, was established, with the aim of identifying strategic priorities for international collaboration.

This meeting established the *Belmont Challenge*, with a focus on *Regional Environmental Change: Human Action and Adaptation.* It aims at delivering knowledge to support human action and adaptation to regional environmental change. Responding to this challenge requires regional and decadal prediction, advanced observing systems and inclusion of social sciences. The objective is *to develop and deliver knowledge in support of national and international government action to mitigate and adapt to global and regional environmental change and its associated regional hazards.*

Regional and decadal-scale monitoring, projections, and adaptation and mitigation strategies are urgently required by decision makers for priority issues such as: coastal zones; water cycle and water resources; ecosystem services and food security; carbon cycling, including ocean acidification; deforestation; land use and soils; and the most vulnerable societies. Research in these areas is central to the provision and utilization of environmental information services for decision-support to governments, business and society at large.

ICSU was charged by the Belmont Forum to conduct an analysis of international research willingness and capability to take action, with a focus on solvability of problems, infrastructure and personnel needed to meet the Belmont Challenge. Responding to the Belmont Challenge will require major advances in the prediction of integrated and comprehensive daily-to-seasonal-to-decadal changes, to improve the utilization and development of observing systems, and to accelerate the integration of natural, engineering, health and socio-economic sciences. There is also a need to build upon existing globally coordinated multidisciplinary, interdisciplinary and transdisciplinary efforts to achieve this objective (see the box on the next page for definitions).

In response to the Challenge, ICSU convened a panel of international leading experts charged with:

- Assessing the willingness, readiness and capability of the international research community to respond to the Belmont Challenge, and provide recommendations for action.
- Addressing issues related to the integration of weather, climate, ecosytem, energy, health, agriculture, engineering and social science research at the regional level.
- Focusing both on the near-term (year-decade) and on the medium-term (20 years) challenges and approaches at the required level of international activity.
- Identifying impediments and how to overcome them.

- Discussing adaptation and mitigation science needs.
- Fostering the necessary collaborative interdisciplinary research activities among international partners.

The primary objectives of the Belmont Challenge are to determine:

- how to address major scientific issues related to environmental changes at the interface between natural and human systems; and
- how to use the resulting knowledge for assessments of impacts, adaptation, vulnerability and the management of associated risks.

Research during the last decades of the 20th century, and into the 21st century, has focused on environmental diagnostics and predictions. The additional focus in the first decades of the 21st century has been to integrate strategies for socio-economic development and environmental sustainability.

Delivering environmental information requires that the issues at the forefront of society's needs be identified. There is an urgency to expand the environmental change research arena by addressing research challenges that mobilize the full spectrum of disciplines, theories and methodologies. We must ensure that individuals and communities participate in the development of research agendas to address social, political and economic problems. Science should provide the basis to assist governments in informing and warning their citizens of impending changes to the environment on daily-to-seasonal-to-decadal timescales, so that actions can be taken to reduce risks, alleviate impacts and benefit from opportunities.

The Belmont Challenge places an emphasis on enhancing the contributions of the *social sciences* to research in global environmental change. This requires that leaders of the social science community engage in all areas related to the agenda of the Belmont Challenge. It is important that social scientists, from the outset, be part of the broader agenda that includes engaging with physical observation, analysis and modeling systems. It is equally important that methods used in the social sciences be understood and appreciated by other scientific communities involved.

The panel recommends that ICSU, in cooperation with the International Social Science Council (ISSC), convene a panel to specifically address the issue of integrating natural and social sciences.

Definitions

Regional Change: Change that occurs over a usually continuous segment of a surface or space often recognized through some common natural or cultural characteristics. A region can cover: a large, almost continental area (e.g. the Asian Monsoon region); a somewhat smaller, though still multi-national area (e.g. the Mediterranean region); or a small area within a country (e.g. the southwestern United States). Understanding the interplay between neighbouring regions and the Earth as a whole is a vital part of understanding the behaviour of the Earth system.

Environmental change: Change that affects different aspects of the social-ecological system including changes in weather, climate, hydrology, ice cover, ecosystems, land-cover and land-use, biodiversity, biogeochemical cycles, chemical composition of air and water, environmental services, etc.

Multidisciplinary: A range of disciplines working on the same problem or question, but with the implications that there are limited or no interactions among these disciplines.

Interdisciplinary: Many disciplines strongly interacting, sharing concepts and approaches, and developing new integrated approaches that span disciplines. Approaches are interdisciplinary when they focus primarily on the integrated system, not only on its components.

Transdisciplinary: Transdisciplinary science refers to research that cuts across social and natural sciences, and includes at least five constitutive features: problem-oriented, beyond disciplinarity, practice-oriented, participatory and process-oriented.

2. Readiness of the Community

The panel discussed the readiness of the community to undertake necessary steps in response to the Belmont Challenge. Most stakeholders (e.g. policy makers and decision makers in diverse socio-economic sectors) concur that *integrated* information is required to develop and implement mitigation and adaptation strategies that more effectively respond to the regional manifestations of global environmental change. However, at present, government frameworks are not always optimally suited to fully respond to the challenges resulting from environmental change. Requirements for advanced weather, climate and other environmental services for diverse socio-economic and environmental sectors focus on time scales ranging from daily-to-decadal, with a strong emphasis on issues that arise at the regional scale.

Scientists are cognizant of their responsibility to address interdisciplinary, global-to-regional issues. However, some believe that their research is primarily guided by fundamental disciplinary challenges and secondarily by societal requirements for scientific information.

Both disciplinary- and societal-driven research are required. There will be important new insights of direct relevance to environmental issues from fundamental basic research, as well as from research defined by society. Intellectual excitement is essential for creativity and innovation. Addressing large complex and intellectually challenging problems requires an institutional framework.

The Belmont Challenge calls for new intellectual and structural approaches. In the past, scientific research was often initiated because it was academically challenging, and secondarily to address a pressing societal issue. The Belmont Challenge calls for an approach in which major cooperative research initiatives are developed from a dialogue between scientists and stakeholders; it is not clear whether the entire research community is fully ready for such an approach. On a positive note, many academic institutions are currently restructuring their curricula to engage in the interdisciplinary and transdisciplinary research needed to solve complex problems that society is facing. There is a growing community within academia, including within the student population, that is engaging in interdisciplinary research of societal relevance.

The *physical-climate, climate-impact and resilience-adaptation-vulnerability* research communities—which, historically, have been separate —must expand their coordination and collaboration. Funding agencies must be encouraged to establish strategic visions that draw these three communities closer together. The physical-climate and the climate-impact communities use, primarily, an approach based on scenario-driven sector impact models, while the resilience-adaptation-vulnerability research community adopts an approach in which climate change is treated as one of the many interacting stresses. These contributions to the Belmont Challenge will be of central importance, since its approach is aligned with what managers at local and regional scales need. Methodologies for impact–vulnerability–adaptation studies should be further developed. Reducing vulnerability and increasing resilience to environmental stress should be a goal for society, including the scientific communities involved. It should be recognized, however, that regional aspects should be developed with a global perspective in mind. Indeed, regional studies must take into account both regional manifestations and impacts of global changes in order to accurately represent the behaviour of the regions of interest.

In past decades, scientific assessments (e.g. those conducted by the Intergovernmental Panel on Climate Change, IPCC) have been important avenues for initiating dialogue between the scientific community and political and economic actors. In the future, these assessments in addition to presenting a critical and expert synthesis of the work conducted by the scientific community, will have to better address broader issues of importance to society.

Addressing the Belmont Challenge requires that a broad range of weather, climate, biogeochemical, geochemical and socio-economic information be collected, coordinated, archived and disseminated. The panel highlights the need for comprehensive and easily accessible databases and for integrated analysis and prediction systems. It notes that:

- Large amounts of Earth system data are available. However, expanded databases are required, e.g. for: surface and ground-water hydrology; oceans; health; public vulnerability/response; and impacts on human and socio-economic activities, and on ecosystems.
- All environmental data should be made openly available to all research users.
- The use of advanced weather and climate data assimilation and prediction systems to combine the best aspects of both data and models (e.g. accuracy and consistency, respectively) is an important aspect of advancing the use and value of multidisciplinary information.
- There is a need to improve long-term, high spatial and temporal resolution observations and predictions that seek to capture extreme environmental and societal events.
- Prediction models need to be tailored to address the integrated science issues posed in the Belmont Challenge. Developing high-resolution global-to-regional Earth system analysis and prediction models, that account for natural as well as human-driven processes, will most effectively be accomplished by strong cooperation between academic, government and risk-management (e.g. insurance) institutions.

3. Impediments

3.1. Funding Structure

In general, academic funding tends to remain mostly structured along traditional disciplines and the level of development of co-designed programmes is less than optimal, e.g. in terms of integration between natural and social sciences. Several attempts have been made by different agencies to develop cross-cutting initiatives. It is increasingly common to see solicitations for proposals by funding agencies that transcend a given discipline.

Co-designed programmes (social and natural sciences) and funding schemes should be developed and coordinated at the local, national and international levels. To complement existing programmes in either natural or social science, the participation of the ongoing international programmes, which have acquired experience in linking different national research communities, would be useful. To be successful, co-designed international projects require long-term scientific commitment and support. Current funding is not optimally structured to address long-term research needs, such as those required to address the Belmont Challenge.

Today's environmental issues are often related to the vulnerabilities and opportunities of specific regions. In some nations, there is a need for enhanced support of scientific research by regional/local governments. Regional authorities should be involved in integrated studies—on subjects such as water, extreme natural events, food and health—in their region.

3.2. Educational Systems

Important initiatives have been taken by the research community to facilitate research and education at the intersection of disciplines. However, many universities continue to emphasize traditional topics and approaches. Specifically, PhD students should be encouraged and supported to address multidisciplinary or interdisciplinary problems. They should also be encouraged to supplement their initial PhD education with post-doctoral training in other disciplines, within natural or social sciences or outside (e.g. humanities).

Students often believe that it is difficult to develop a successful career without a strong specific disciplinary focus. However, there are clear exceptions, for example, geography, anthropology and economics. Similarly, natural scientists are often reluctant to engage in the socio-economic integration and application of their science. The present reward/recognition system at most universities is not sufficiently conducive to what is required to meet the Belmont Challenge.

Some academic institutions have recently established inter-disciplinary, multi-departmental research institutes that focus on climate and social-ecological issues, and developed Earth system science undergraduate and PhD programmes that provide opportunities to address the Belmont Challenge. The introduction of curricula linking natural sciences, engineering and socio-economics (e.g. economics of environmental change, risk management) should be encouraged.

The education system should encourage post-doctoral researchers to expand their interdisciplinary engagement. Academic and governmental institutions should develop interdisciplinary visiting programmes with international and multi-cultural participation.

Addressing the Belmont Challenge requires a strong engagement with universities and the research branches of operational agencies. The interplay of environmental issues with engineering should be enhanced.

3.3. Infrastructure and Facilities

The infrastructure to address environmental issues, especially at the regional scale, has often been developed separately by the natural science and socio-economic communities, and government service providers. Today, information provided by these communities and providers needs to be integrated into a single framework. This task is a major challenge, since the vocabulary, methodologies and approaches adopted by the different communities differ significantly. In certain cases, the lack of spatial disaggregation of environmental and economic data are incompatible with the needs of natural scientists. For example, trace gas emissions compiled by official authorities in different countries are often provided as single values for the entire country, while environmental models require highly spatially resolved geographic distributions of these emissions.

Monitoring environmental conditions is important to assess the vulnerability of societies and to develop mitigation and adaptation strategies. In order to support long-term monitoring activities, there is a need for better cooperation between agencies that fund research—across the spectrum from basic research through to operational research. Progress would be made if the funding for essential observing systems were successfully transitioned from project-based research funding to ongoing operational funding. A major challenge in sustaining and updating observational capabilities is to demonstrate their effectiveness and impacts (e.g. on research, analysis, data assimilation, forecasting). Currently, only a small fraction of available observations are used for research and operation due to a variety of issues, including lack of access, restrictions by some nations, inconsistency in processing and documenting the different products, complexity of the algorithms used, difficulty in use and interpretation by non-experts, and lack of training.

Integrated environmental studies utilize information produced by different research and operational institutions. The panel believes that there is inconsistent support provided to enable integration of data and to check data quality. While there is sufficient work in some areas (due to sufficient support), existing work is insufficient in others. For example, there is an important issue that arises regarding the units of analysis when integrating natural science and social science efforts. While social science data are almost always collected in terms of political/administrative units (e.g. census tracts, municipalities, provinces, nations), natural science data are usually collected based on regular spatial intervals (e.g. a grid of 5 km). A major challenge for all of us, therefore, will be to find a way to harmonize the resultant data sets. In many instances, access to existing data remains limited by restrictive information-sharing policies. Environmental data acquired by public funds should be accessible to scientists. In addition, international programmes should play a major role in evaluating the consistency of related data sets and in producing and evaluating unified data sets that incorporate the data products from multiple providers. Initiatives should be taken to develop visualization of data with emphasis on data and systems that are accessible to non-specialists.

Finally, the panel highlights that the development of a family of Earth system prediction models—that include a representation of physical, chemical and biological details at global-to-regional scales with sufficiently high spatial resolution—cannot be achieved without access to dedicated supercomputing facilities. Even though much support has been provided for the installation of supercomputing systems by some countries, challenging problems require even more powerful machines. For example, models that resolve clouds, hurricanes and strong precipitation, urban air quality, surface hydrology, local environmental conditions and ecosystem status, require development of and access to much more powerful machines. Grid and cloud computing are playing an increasingly important role in many disciplines; these approaches will be particularly useful in fostering collaborative research in Earth system research. Their development should be encouraged.

4. Road Map to Address the Belmont Challenge

The panel proposes a road map to facilitate the implementation of the Belmont Challenge by considering the identification of issues and the approaches needed to address these issues.

4.1. Identifying key issues

In order to identify the key issues within the Belmont Challenge, it is crucial to improve the dialogue between the scientific community and the diverse stakeholder communities, especially at the regional level. There is a need for an iterative, interactive process, involving both communities engaging in dialogue to identify and analyze issues and questions (originating from this dialogue), and to determine their significance. At the same time, scientists should engage in dialogue among the disciplines in order to develop responses to the needs of society. Ultimately, the identification of the key issues should involve both stakeholders and scientists.

Discussions conducted at the international level, often involving stakeholders, have identified important research questions to be addressed for better management of planetary resources. In its early definition of the Belmont Challenge, a few near-to-mid-term foci were identified:

1. coastal zones in the 21st century: ecosystems, people, commerce and security;
2. water quality and water resources: availability and distribution;
3. sustainable carbon-based economy, including ocean acidification, deforestation, land use and soils; and
4. the most vulnerable societies, with low-response capacity and with high societal vulnerability to environmental changes.

Other issues will be raised through the dialogue with stakeholders. Here, the participation of social scientists (e.g. economists, political scientists, sociologists and psychologists) will be crucial. Illustrative examples of issues that need to be addressed by these communities of scientists are provided in the box on the following page. A broad engagement of social scientists—from different communities and different regions of the world—is necessary to identify not only the specific social science questions that the Belmont Challenge raises but also the social science perspectives that must be brought to bear on the full range of priorities identified—predictions and observations included.

Illustrative example: Broad societal issues for the Belmont Challenge

A key challenge is to understand the roots of human behaviour as it pertains to human-environment interactions. It is important to understand how and when major behavioural changes occur.

Within this framework, some of the focus should be on:

- top-down approaches featuring public policy making and implementation;
- bottom-up approaches featuring the role of social movements;
- the role of institutions and, more specifically, governance systems;
- decision-making under uncertainty, including the roles of rules of thumb and heuristics (educated guess, intuitive judgment or common sense) and the role of local or traditional knowledge, as well as religious or spiritual beliefs; and
- human security, specifically options available to individuals and communities to stop, to mitigate or to adapt to environmental change and related social vulnerabilities, and their capacities to do so.

4.2. Addressing the issues

Responding to the Belmont Challenge will require that the scientific community: (i) enhance its understanding of the multiple stressors affecting the environment, their combined impacts and feedbacks, as well as the vulnerability of ecosystems and society; (ii) better quantify the rates of change, the controlling factors and feedbacks at relevant spatial and temporal scales; and (iii) assess the environmental and societal consequences of mitigation and adaptation strategies. These issues will be addressed by:

- Developing and evaluating the next-generation of Earth system models coupled to observations.
- Developing a diagnostic and projective capability for societal and ecological vulnerability.
- Developing decision-support tools to map out how policy decisions affect future environmental and societal changes.

These issues require more effective use and further development of four elements:

1. observation and monitoring systems;
2. analysis and prediction systems;
3. information and communication tools; and
4. capacity building capability.

1. Elements of global and regional environmental and socio-economic observation systems and data management

The *first element* is the development of more effective uses of existing observations. The research community will need to define and advocate for additional *observation* and *monitoring information* systems to respond to the Belmont Challenge. The focus should be on observations that characterize the dynamics of a region, e.g. weather and climate variations and trends, extremes, vulnerabilities of both social systems and ecosystems, and societies as drivers of change and at risk from change. This will include different aspects of environmental and socio-economic evolution, e.g. extreme weather and other disasters, fires and air pollution, as well as economic and social benefits and impacts. The panel recommends that a few regional pilot projects be initiated in selected societally and environmentally vulnerable regions. Attention should be given to natural and human drivers of change and subsequent responses. Opportunities to use existing and future observation platforms (e.g. in space, or on aircraft, ships or land) as well as using dedicated platforms, should be fully exploited.

Examples of information needed from observation and monitoring systems

- Regional and local information on forcing and response, e.g. land cover and water resources.
- Environmental parameters with high spatial/temporal resolution, to be able to describe the frequency and spatial distribution of extreme events.
- Socio-economic data, including systematic mapping and assessments of costs associated with disasters at global, regional and local scales. These data should be obtained with consistent methodologies for assessment of natural hazards proceeding from the probability of their occurrence and recurrence and using empirical, statistical, and deterministic approaches to enable estimates of hazard potential, affected areas and impact duration.

2. Integrated Earth system analysis and prediction systems

Earth system science integrates observations, research, monitoring and prediction of the most probable evolution of the Earth system in response to natural forces and human activity. It synthesizes, integrates and assimilates *in situ* airborne and space-based Earth observations, together with human-dimension information, into comprehensive and consistent four-dimensional descriptions of the evolving Earth system. Such analyses form the basis for projections/predictions by dynamic Earth system models, e.g. ensemble prediction models, regional coupled models, statistical and neural network models. Dynamic downscaling will meet some of the user-needs at local and regional scales for socio-economic, agro-meteorology, human health, policy, resource, threat, risk and adaptation-mitigation applications.

The *second element* is the development of integrated regional *modeling tools* for analysis and projection/prediction, in support of environmental management (risks, vulnerability and adaptation) and provision of information. Here, priorities are the development and evaluation of a hierarchy of models, and their use to diagnose and analyze the past evolution of environmental and socio-economic systems, to predict the future state and to characterize vulnerability and risks. This requires the development of a hierarchy of Earth-system models with regional capability that includes a representation of coupled physical, chemical and biological processes. High resolution multi-model (ensemble) simulations for different scenarios should be performed. A wide range of environmental issues need to be considered, including climate change, flooding, droughts, tropical cyclones, sand and dust storms, winter storms, land-use changes, overexploitation of marine resources, loss of biodiversity, ocean acidification, lake eutrophication, air and water pollution, toxins, invasive species, and perturbation of biogeochemical cycles. The focus of these modelling studies should be on trends, abrupt changes and the probability of occurrence of future extreme events.

Some important considerations are improving the skill for prediction on daily-to-inter-annual timescales, and assessing decadal-to-centennial predictability limits and the predictive skills of models. This requires that predictive skills be investigated for past variability and change. The relationship between information required for model initialization and subsequent predictive skill should be addressed. Since decadal predictions of high-impact local events are still over the horizon and any information from such predictions is likely to be probabilistic, scenario-based projections will remain a useful approach as input to decision-making. Here, scenario development and analysis should be developed as a tool for structuring interdisciplinary discussions at the regional level, taking into account the global context in which regional changes take place. Clearly, the new generation of models should take the human dimension into consideration. The panel emphasizes that a decision-information system regarding hazards, risks and responses will benefit from advanced data assimilation systems coupled to high-resolution models.

The panel believes that the long-term goal is the *development of integrated Earth system analysis and prediction systems*. By fully engaging with the relevant disciplines and communities, it will be possible to develop integrated observing, analysis and prediction systems that address coupled atmospheric, land, ice, biosphere and oceanic components and their future evolution under severe human-related stress.

To accelerate progress in this area, the following recommendations are made:

- Accelerate collaboration between the meteorological, oceanographic, hydrological, ecological, and climate communities, and share methodologies and software, e.g. model-to-observation software, diagnostics packages.
- Converge internationally on a limited number of appropriate models that will be developed by a large, interdisciplinary community of scientists.
- Develop and assess decadal prediction systems as extensions to existing seasonal forecasts systems.
- Concentrate investments in high-performance computing that will allow a rapid increase of resolution for forecasting systems through improvements in the representation of physical, chemical and biological processes.
- Encourage investments in observing systems and implement the transition of research findings into operational services, particularly in the case of ocean observations.
- Secure new funding for historical Earth system re-analysis and re-forecast activities.

Another important challenge is the development of a *prediction/projection capability for the characterization of vulnerability and risk* (personal, health, economic) and response strategies (resilience, insurance). Here, key research questions are: How vulnerabilities (e.g. population, infrastructure, economic activity and livelihood, health) can best be determined and portrayed in a way that provides the critical information required by policy makers and decision makers? How can appropriate adaptation measures best be identified, evaluated and prioritized? Who and what are the people and places most at risk and why? And, how might the risks change with time?

It will be important to consider models at various scales, able to run multiple scenarios and ensembles in order to get a probabilistic distribution of results. As model simulations become available, uncertainties will have to be quantified to the maximum extent possible. The differences in the uncertainties coming from the different models will have to be addressed through model-model and model-data inter-comparisons.These model results will support future international assessment activities.

Illustrative example: Towards a seamless weather, climate and Earth system prediction system

1. Advances in the representation of physical processes (e.g. tropical convection, atmosphere/ocean/land/ice interactions, aerosols, cloud microphysics and radiation, boundary layer turbulence) and their interactions with the global circulation will lead to more skilful predictions of regional to global weather and climate. This success will translate into socio-economic applications for improving early-warning systems for weather- or climate-induced hazards. Applications could be for agriculture, the water cycle and its management, or health—particularly in regions affected by monsoons.
2. Advances in coupled data assimilation are a prerequisite for long-range weather and climate predictions. Historically, data assimilation research and its applications have focused mostly on the requirements of operational short- to medium-range weather forecasts. The next generation of assimilation and re-analysis projects will have to integrate information provided by climate, weather and Earth system research programmes.
3. An important requirement is to build satellite missions and implement planned ones that provide long-term capability for process studies, data assimilation and prediction.
4. High-performance computing and archive centres will be required to enable efficient numerical modeling, advanced experimental design, improved data processing and distribution of data (including relevant socio-economic information and analysis).

3. User-Interface: Environmental service in support of informed decision making

The *third element* is to develop *information/communication tools*, or more generally *integrated Earth system knowledge platforms* to provide scientific results to stakeholders and specifically to policy makers and decision makers/managers. Here, it is important to advance the two-way communication system between science and society. Information must be objective and easily accessible. New media and communication technologies are very important tools and they should be fully exploited. Direct dialogue with stakeholders is an important component of a communication system. Working with information providers and disseminators, including teachers and journalists, should be encouraged. Communication should emphasize the probability of occurrence of key parameters that are badly needed by policy makers and decision makers/managers.

It is necessary to integrate stakeholder consultation with research across a wide range of Earth science disciplines, engage the private sector, and to do so in partnership with various national efforts. One important element is to identify the stakeholder needs for Earth system observation and prediction products. Recently, national leaders, investors, business leaders and policy makers have begun to seek strategies to help prepare for the adverse and beneficial impacts of environmental change on business, industries, local communities and entire nations. Unfortunately, decision makers are not yet fully provided with the information needed to develop cost-effective strategies to reduce vulnerabilities, such as:

- the probability of various types of climate change happening in a particular geographic region from seasons to decades;
- the vulnerability of various natural and human systems in this geographical region to environmental changes; and
- the costs and benefits of strategies to reduce vulnerability.

The establishment of a Global Framework for Climate Services[2] provides an opportunity for developing bridges between research, operations and society. The Framework must integrate knowledge on multi-stressors affecting social and ecological systems and the complex feedbacks that exist between different components of the Earth system. Hence, the Framework will provide information as an extension of current national meteorological and hydrological services. They must embrace the physical climate system, biogeochemistry and socio-economic sciences. This approach presents research, personnel and capacity challenges across the disciplines. The service function should remain coupled to research. The focus should be on impacts, vulnerability and adaptation.

Providing information on the global and regional environment that specifically supports human action and adaptation to environmental change requires that research funding agencies and their constituencies coordinate closely with operational funding agencies.

[2] The decision to establish a Global Framework for Climate Services was made during the High Level Segment of the World Climate Conference 3 in Geneva, 31 August–4 September 2009. More information on the Framework can be found at: http://www.wmo.int/wcc3/declaration_en.php

Illustrative example: Towards the quantification of human and economic risks associated with environmental changes

- Develop products (observation and model) on a regular basis, tailored to users' needs, including those for specific regions and sectors.
- Run models responsively for multiple scenarios in ensembles to provide uncertainty estimates.
- Develop data delivery systems to provide results to users.
- Include socio-economic information so human and economic costs of risks and impacts can be characterized and/or estimated.
    - Modeling of risk requires the integration of natural and socio-economic sciences—how to do best is a key research question. Risk assessment and modeling, and the provision of evidence-based scientific advice require natural and social scientists to collaborate. Modeling of risk requires the development of holistic models incorporating natural processes, infrastructure, societal factors and human behaviour.
- Support extensive multi-disciplinary quantitative analysis of model outputs, especially to identify potential unintended consequences of changes.
    - Development of risk models, which can incorporate both quantitative and qualitative information will allow for the comparative analysis of different approaches towards risk reduction. Scientists undertaking this research should work closely with local communities and authorities so that science is integrated into societal concerns and policy development.
- Provide comparative analysis and integrative approaches that analyze the context and related risks, vulnerabilities and projected impacts from both the top-down (i.e. downscaling) and bottom-up (i.e. critical thresholds approach)—resulting in additional research insights and benefits for users.
- Communicate uncertainty in forecasts and risk assessments to decision makers and the public—this is a challenging task, for which drawing on local indigenous knowledge systems will help.
- Address decision making in governance and society—political, economic, social factors. Identify key obstacles/barriers to urban adaptation to environmental change, including knowledge gaps, human and financial resources and institutional capacity.

4. Capacity Building

The *fourth element* is to develop a *capacity building strategy*. Such a strategy will apply to both developing and developed countries, with particular attention to the needs of the societies under greatest stress. Capacity building requires a sustained approach. This can be facilitated by education programmes, especially in developing countries, as well as supporting infrastructure—especially for data delivery, archiving, and visualization. Extensive opportunities should be provided for scientists from developing countries to visit leading institutions around the world—to share experiences and help build a global scientific community. Opportunities should be created for early career scientists, especially those from developing countries, to work alongside established scientists (e.g. on field campaigns and assessments). Two-way partnerships between scientists and institutions from developed and developing countries should be established.

5. Instruments and Suggested Initiatives

The panel concludes this report with suggestions to facilitate the implementation of activities that respond to the Belmont Challenge, recognizing that many of these ideas are presently under consideration by the scientific community. In particular, the recent ICSU-led visioning process—to develop a holistic strategy for global sustainability research—is exploring options for a new institutional framework to meet the five grand challenges that have been identified as part of the visioning process. The following suggestions, which should build on the experiences and capacities from the existing global environmental change programmes and activities, may also provide useful inputs to the ongoing visioning process.

5.1. International Research and Educational Network for Earth System Science (IRNESS)

Create an International Research Network for Earth System Science (IRNESS) with access to state-of-the-art facilities, including interdisciplinary databases and high-capacity supercomputing. This network of centres will host staff and visiting scientists, develop a strong interdisciplinary focus towards integrated Earth system science and support regional initiatives. Its agenda will be broad and highlight integrated, interdisciplinary aspects of environmental sciences (physical climate system, social-ecological system). It will focus on regional and global environmental issues, including: climate change; land use/cover changes; chemical pollution; loss of biodiversity; human health under environmental stress; adaptation and mitigation policies; and international negotiations. It will be accessible to scientists from around the world. The network will facilitate an international programme that brings together the knowledge needed to support dialogue that contributes to adaptation measures and environment management. The network will build upon existing academic and government agency centres and will include virtual components linking participating institutions. The centres will be connected through modern telecommunication facilities. The network will offer training classes for scientists and other stakeholders and will offer a post-doctoral programme and a senior visitor programme.

Develop an international doctoral programme for interdisciplinary Earth system science. Support and expand existing initiatives that attract students from different disciplines and from around the world. Within a network of universities and other research institutions, the programme would provide an international Earth system curriculum that would bridge natural and social sciences. In addition, it would organize summer schools, where students from all around the world could be exposed to and exchange perspectives on issues and their impacts in different regions.

5.2. Pilot Studies

Conduct interdisciplinary pilot studies in selected regions with the purpose of developing mitigation and adaptation strategies to natural and human-induced environmental changes. Such studies should be coordinated by scientists from the region and should be regarded as regional Earth system integrated studies.

6. Conclusions

The environmental problems facing today's society cannot be overcome by a single nation or a single scientific discipline. Responding to these adversities demands highly coordinated and collaborative research and operational service agendas. The proposed agenda in this report will lead to the provision of the scientifically based information needed by local, national and international decision makers as they take actions for the benefit of society and environmental sustainability.

The panel concludes with the following requirements:

- At a time of globalization, environmental and development issues need to be addressed at the international level. Countries, as well as agencies within individual countries, need to increasingly work together to coordinate and support research required to address global societal needs. The challenge is to integrate in a single framework environmental and economic issues that have been largely addressed separately in past decades.
- An integral component of the Belmont Challenge is to develop and maintain a two-way dialogue between scientists, policy makers and the general public by which scientists provide answers that are pertinent to the questions posed by society.
- It is important to maintain and expand the access and the use of the current global observing and monitoring systems, to coordinate databases and to develop assimilation procedures with the purpose of gaining maximum benefit from these observations. It is equally important to contribute to the development of new observing systems, both physical and societal.
- Society increasingly requests detailed regional and site-specific information. Earth system models should provide high-resolution predictions at the timescales of days-to-seasons-to-decades; this requires the next generation of prediction models to achieve a higher degree of useful predictive skill and to represent high-resolution processes, such as weather and surface hydrology changes and their interactions with socio-economic activities at seasonal to decadal time scales.
- The most advanced and powerful dedicated supercomputing facilities are required to resolve key high-resolution physical, chemical and biological processes as well as human activities and treat the full complexity of these issues.
- It is important to expose a new generation of natural and social scientists to environmental observations, analyses and predictions and to communicate the excitement and challenge of integrating complex Earth system processes into daily-to-decadal weather and climate predictions.

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The report has benefited from the critical and constructive comments and suggestions from Will Steffen, Kevin Noone, Mark Stafford Smith, Holm Tiessen, Robert J. Scholes, Bruce McKellar, Ronald F. Abler, Alice Abreu, Ghassem Asrar, Tom Beer, Michel Béland, Stephen Carpenter, Ian Dowman, Anantha Duraiappah, Bryan Henry, Maurizio Iaccarino, John Ingram, Hartwig H. Kremer, Anne Larigauderie, Harold Mooney, Alice Newton, Gabriel B. Ogunmola, Hans-Rudolf Ott, José-Antonio de la Peña Mena, Carolin Richter, Pierre Ritchie, Thomas Rosswall, Sybil Seitzinger, Rainer K. Silbereisen, and Alik Ismail-Zadeh.

Acknowledgement: We thank US-NSF (grant GEO-0837928, amendment no. 003) for support of this project.

Layout by: Carmela Garipoli

Printing: Caractère (France) using 100% PEFC certified paper

PHOTOS :

Cover: top left: IRD/Bernard Moizo, top right: Gilles Graber, centre left: flickr/jmm403, centre right: IRD/Olivier Barrière, bottom left: Photolibre.fr, bottom right: ESA

Back cover: top left and centre right: ESA, top right, centre left and bottom left: Photolibre.fr

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Grand Challenges in Global Sustainability Research: A Systems Approach to Research Priorities for the Decade

6 August 2010

The International Council for Science (ICSU) proposes to mobilize the international global change scientific community around an unprecedented decade of research with the aim of delivering knowledge needed to achieve sustainable development. *In doing so it seeks to work in close collaboration with the International Council for Social Sciences (ISSC) and other partners. The pace and magnitude of human-induced global change is currently beyond human control and is manifest in increasingly dangerous threats to human societies and human well-being. There is an urgent need for the international scientific community to develop the knowledge that can inform and shape effective responses to these threats in ways that foster global justice and facilitate progress toward sustainable development goals. The global change research community, which has played a central role in understanding the functioning of the Earth system and the human impacts on that system, holds the promise to meet this need. Realizing that promise requires a focus on new research priorities, and on new ways of doing and using research to address needs at global, regional, national, and local scales. This report is the product of an international consultative process led by ICSU and its partners that was designed to: (a) identify broadly-accepted grand challenges in global sustainability research; (b) identify high priority research that must be carried out to address those challenges; and (c) mobilize scholars in the sciences (social, natural, health, and engineering) and humanities to pursue that research.*

Introduction

The study of the Earth system – the social and biophysical components, processes and interactions that determine the state and dynamics of the Earth including its biota and human occupants – has reached a point of transition. For the past two decades, our priority has been to understand the functioning of the Earth system and, in particular, the impact of human actions on that system. Science has advanced to the point that we now have a basic understanding of how human actions are changing the global environment and a growing understanding of how those changes will affect society and human well-being. This research has provided invaluable insights regarding the biophysical processes that determine the functioning and resilience of planet Earth, the sensitivities of different components of the system, evidence of the accelerated pace of global environmental change caused by the human enterprise, the possible consequences of those changes, and the human dimensions of how to address these challenges.

This science also tells us that the rate of global environmental change is, so far, vastly outpacing our response and, thus, that our current path is unsustainable. We know enough to state with a high degree of scientific confidence that without action to mitigate drivers of dangerous global change and enhance societal resilience, humanity has reached a point in history at which changes in climate, hydrological cycles, food systems, sea level, biodiversity, ecosystem services and other factors will undermine development prospects and cause significant human suffering associated with hunger, disease, migration, and poverty. If unchecked or unmitigated, these changes will retard or reverse progress towards broadly shared economic, social, environmental, and developmental goals.

Our existing knowledge provides a useful basis for vital activities needed to manage specific parts or features of our world in transition, but it falls well short of what can be considered integrated solutions. How can we change human behaviour and shape political will so as to make it possible to meet targets for reductions in greenhouse gas emissions that will avoid dangerous climate change? How can societies most effectively and equitably respond to the global change that is already underway? How can they eradicate extreme poverty and hunger and achieve environmental sustainability?

The international scientific community holds the promise of delivering the knowledge necessary for answering these crucial questions. But realizing that promise will require a refocusing of research priorities and a reorientation towards new research frontiers. We will have to meet a twofold challenge, namely to develop response strategies to global change, on the one hand, and to deepen our knowledge of the functioning of the Earth system and its critical thresholds and the on the other hand. This will require new ways of doing research that better link science and society to address the needs of decision-makers and citizens at global, regional, national, and local scales.

Over the next decade the global scientific community must take on the challenge of delivering knowledge required to support efforts to achieve sustainable development in the context of global environmental change. Solution-focused, strategic, interdisciplinary, long-term research is needed to improve our knowledge of the social-environmental risks facing humanity and to provide science-based support for actions to achieve sustainable development. We rapidly need to deepen our understanding of how the Earth system operates in response to human pressures, improve our ability to predict future risk patterns, and explore social transformations in the world that can overcome barriers to sustainability. We refer to this field as "global sustainability research." [1] Global sustainability research builds upon and integrates expertise within the sciences (social, natural, health, and engineering) and humanities and applies it to pressing coupled social-environmental research questions of human interactions with the Earth system.

Just as we are at a point of transition in the focus and scale of global social-environmental research, we are also at points of transition in the disciplines that must be involved and the processes by which that research is undertaken. There is a need for transitions from:

- *Research dominated by the natural sciences to research involving the full range of sciences and humanities.* Social sciences have long been a component of Earth system research, but tackling the grand challenges described here requires a stronger involvement and greater

[1] We consider the field of "global sustainability research" to be largely equivalent to "Earth System research," but with a more explicit recognition of the human dimension. The Earth System is defined as the unified set of physical, chemical, biological, and social components, processes and interactions that together determine the state and dynamics of the Earth, including its biota and its human occupants. Although Earth System science includes humans as an integral component of the Earth System, this term is seen by many to focus primarily on the natural system. The term "global sustainability research," helps to give greater emphasis to the central importance of the social sciences in this research agenda.

integration of the social sciences, health sciences, engineering and humanities, along with the natural sciences. It is increasingly clear that pathways to address rapid global change can only be found through inquiries that integrate the full range of sciences and humanities in ways that may lead to significant transformations in these disciplines as they are currently understood. It also requires the inclusion of local, traditional and indigenous knowledge.

- *Research dominated by disciplinary studies to a more balanced mix of disciplinary research and research that draws disciplinary expertise into an integrated approach that facilitates inter- and transdisciplinarity.* The solutions to the grand challenges must be rooted in disciplinary research, but disciplinary research alone will be insufficient. Many of the priority research questions can only be solved through effective interdisciplinary research. Moreover, it is clear that both research progress and the effective use of scientific results by society and decision-makers can often be enhanced through transdisciplinary research; that is, through greater involvement of external stakeholders in the research process. Research will often be most useful, and the results most readily accepted by users, if priorities are shaped with the active involvement of potential users of research results and if the research is carried out in the context of a bi-directional flow of information between scientists and users. An effective response to global environmental change will be aided by the co-creation of new knowledge with a broad range of stakeholders through participatory practices.

These proposed transitions in the disciplines involved and the research processes utilized are needed because they will bring greater expertise to bear in framing and addressing the research priorities, because they help to ensure that the research priorities are relevant to key stakeholders, and because the answers to the research questions can more readily inform decision making.

In light of the urgent needs, ICSU[2] is seeking to mobilize researchers around an unprecedented, 10-year scientific effort to address the grand challenges in global sustainability. The process to reach consensus on the grand challenges and research priorities began with an Internet consultation in July and August 2009.[3] The Internet consultation yielded more than 300 proposed Earth system research priorities contributed by individuals from 85 countries. These proposed research priorities formed the background for a workshop held in September 2009 involving senior researchers, early career scientists, science-policy experts and representatives of research funding agencies. A draft document presenting the selection criteria, grand challenges, and research priorities generated by

[2] Founded in 1931, the International Council for Science (ICSU) is a non-governmental organization representing a global membership that includes both national scientific bodies (121 National Members representing 141 countries) and International Scientific Unions (30 Members). The ICSU 'family' also includes more than 20 Interdisciplinary Bodies (IBs)—international scientific networks established to address specific areas of investigation. These IBs are either co-sponsored or uniquely sponsored by ICSU and include the four global environmental change programmes: World Climate Research Programme, International Geosphere-Biosphere Programme, International Human Dimensions of Global Environmental Change Programme, and DIVERSITAS. Through this international network, ICSU coordinates interdisciplinary research to address major issues of relevance to both science and society. In addition, the Council actively advocates for freedom in the conduct of science, promotes equitable access to scientific data and information, and facilitates science education and capacity building.

[3] The full process is described in detail at: http://www. icsu-visioning. org/the-visioning-process/. The Internet consultation (www. icsu-visioning. org) attracted over 7000 unique visitors from 133 countries and over 1000 registered users from 85 countries, who posted research questions, made comments and voted on the questions. By the end of the consultation, 323 distinct Earth system research questions had been posted on this moderated site.

that workshop was circulated for review between December 2009 and March 2010. Review comments from 46 institutions and over 200 individuals have been addressed in this report.

This report aims to provide a widely shared vision of the scientific priorities for global sustainability research in the coming decade. It is intended to: a) mobilize the greater engagement of the international scientific community and, particularly, of the broader social science community, in global sustainability research; b) stimulate innovative new research and guide the prioritization of research topics by scientists, research funders and policy makers; and, c) inform potential users of the findings that might stem from this research, including scientific assessments like the Intergovernmental Panel on Climate Change, and technical advisors to decision-makers in the private sector and governments. Representatives of these stakeholder groups are the audience for this document and have been involved in its development. Additional information on this consultative process is provided in the Appendix 1.

Criteria

We have used the following criteria in selecting the grand challenges and associated research priorities.

1. **Scientific importance.** Does the question address a cutting-edge research challenge that, if answered, could significantly advance our understanding within the next decade of how to achieve global sustainability?
2. **Global coordination.** Is a coordinated international or global approach involving multiple researchers in different regions and often in different disciplines needed to answer the question? If not, then such a question would fall to others (i.e., be outside the remit of this framework, despite its importance to a given field).
3. **Relevance to decision-makers.** Will the answer to the question help to inform actions to meet urgent global social and ecological needs, especially promoting sustainability, reducing poverty, and assisting the most vulnerable in coping with global environmental change?
4. **Leverage.** Does the answer to the question involve a scientific or technical breakthrough, or would it create a transferable theory, model, scenario, projection, simulation or narrative that would help to address multiple problems or other challenges related to global sustainability research?

In addition to these four criteria used for both the selection of the grand challenges and the research priorities, the five grand challenges were also screened against a fifth criterion: did the proposed grand challenge have broad support from the research and funding community (even those not directly involved in answering the question). We believe that each of the grand challenges is widely perceived to be a fundamental question that must be addressed in the pursuit of global sustainability. In the case of the research priorities, we also added a criterion focused on the feasibility of the research: Is it plausible that the question can be answered within the next decade? We are confident that we have the scientific basis and tools available to answer the research priorities listed in this document, but success will require adequate resources and effective coordination of the international research community to ensure that the questions are addressed with focus and intensity.

The Grand Challenges in Global Sustainability Research

Consistent with the use of the concept of grand challenges in other areas of science, we consider the grand challenges in global sustainability research to be a call for scientific innovation or understanding that would remove critical barriers to deciding how to achieve sustainable development. We list five grand challenges in global sustainability. Within each, we list several top-level research priorities that must be addressed during the next decade to make significant progress in resolving the problem posed by the grand challenge. The list of research priorities is neither exhaustive nor necessarily sufficient. Nonetheless, it is our judgment that these questions must be addressed to achieve the most rapid progress. In virtually all cases, a deep base of research and knowledge already exists in the areas identified by these research priorities and, building on that base, it is thus plausible that the research area can be substantially advanced in less than a decade. However, it is by no means inevitable that all the questions can be answered. These are, by definition, big and difficult problems, and will require a focused, multidisciplinary, and integrated research commitment to have a reasonable prospect of success.

The resulting challenges cover a diversity of topics but are united as elements of a systems approach to global sustainability research that examines how the coupled social-environmental system is changing (including the dynamic responses of people and the environment) and what actions and interventions may alter the environmental and social outcomes. (See Figure 1.) The grand challenges adopt a systems approach from the perspective of what is being studied: the full social-environmental global system rather than independent components of that system. They also adopt a systems approach from the perspective of how research can inform actions to achieve global sustainability: none of the challenges can be fully addressed without progress in addressing the other challenges.

Consequently, the five grand challenges are an indivisible package, and the topics are not prioritized either across or within the challenges. Progress on every one of the challenges and research questions is urgently needed. The global sustainability research community has unique capacities to contribute to the solution of these challenges, but all of them will require working with partners outside of this research community as it currently exists.

Challenge 1. Forecasting: Improve the usefulness of forecasts of future environmental conditions and their consequences for people.

Priority Research Questions

1.1. **What significant environmental changes are likely to result from human actions? How would those changes affect human well-being, and how are people likely to respond?**

1.2. **What threats do global environmental changes pose for vulnerable communities and groups and what responses could be most effective in reducing harm to those communities?**

We consider a "useful" forecast to be one that is responsive to the needs of societies and decision-makers for information at relevant spatial and temporal scales and is timely, accurate, and reliable. Our limited ability to anticipate the outcomes resulting from the interaction of complex and diverse

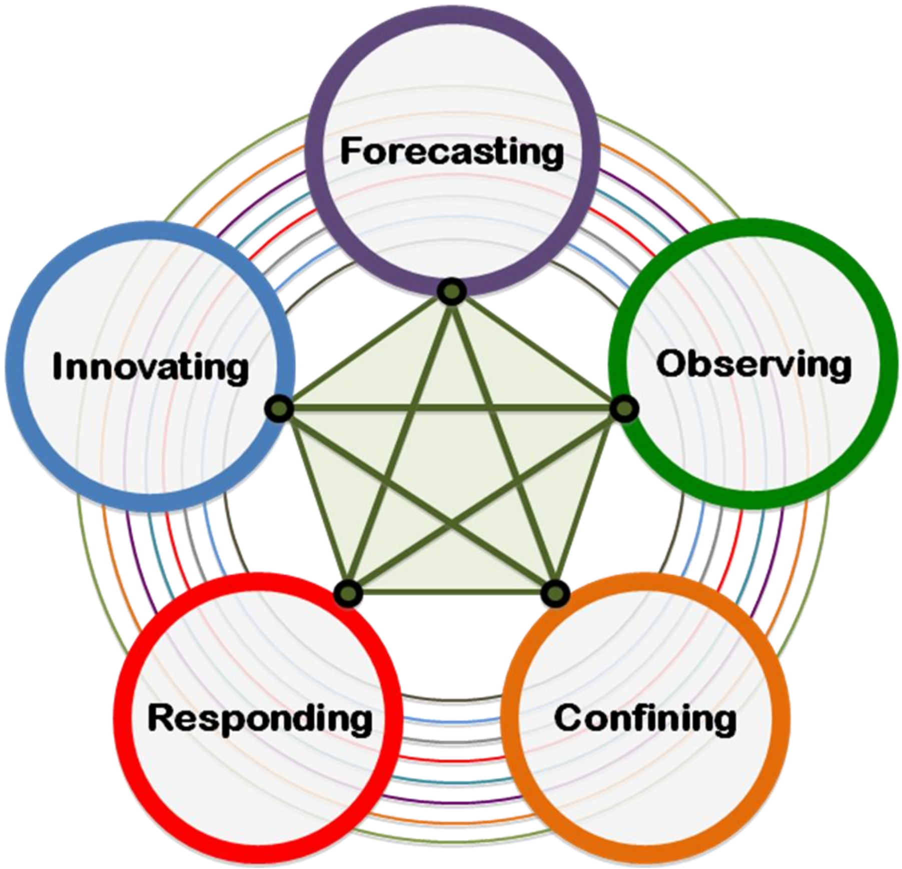

Figure 1. Grand Challenges in Global Sustainability Research. The concentric circles represent the disciplinary research needed in the social, natural, health and engineering sciences and the humanities that must be carried out alongside interdisciplinary and transdisciplinary research in order to address the challenges. The lines linking the grand challenges show that progress in address any challenge will require progress in addressing each of the others.

human societies with equally-complex natural processes is a significant barrier to timely and effective decision-making and action. Although we may never be able to accurately forecast the future of coupled social-environmental systems beyond a time horizon of several decades, there is tremendous potential to improve our ability to use scenarios and simulations to anticipate the impacts of a given set of human actions or conditions (e.g., population size, levels of consumption, greenhouse gas emissions, deforestation, increased agricultural productivity, etc.) on global and regional climate and on biological, geochemical, and hydrological systems on seasonal to decadal time scales. Building on this work, significant advances are now also needed in our ability to assess the potential impact of those environmental changes on human well-being (e.g., impacts on economies, health, food security, energy security, etc.) and the potential human response to such changes. Such forecasts and assessments should be tailored to respond to the questions and needs of the people potentially affected, and the uncertainty should be quantified and clearly communicated.

Answering the research questions posed here will require a major new scientific endeavour to build the capacity to predict changes to the Earth system as a core contribution to global sustainability research. It includes a pressing need to develop a new suite of Earth system models with the ability of predicting changes to the Earth system from anthropogenic influence at global, regional and, where possible, local scales. This will necessitate major scientific advancements in integrated analyses of the dynamics of interlinked biophysical systems on Earth and coupling these with the human dimensions of global environmental change, both in terms of drivers and impacts. This in turn will have to build on continued progress in disciplinary Earth system research, and major improvements in and intensification of Earth observation systems.

Science cannot, as yet, provide adequate predictions of the Earth system response to pressures from the coupled socio-environmental complex. This is a major dilemma for humanity as a whole. We know that humanity is pushing systems on Earth towards risks that may cause abrupt, and potentially irreversible and disastrous changes. Despite major advancements in Earth system science over the past decade, the uncertainties and risks of anthropogenic change remain too high for comfort.[4] Human development continues along a dimly lit path of uncertainties and risks; in the absence of clarifying headlights policymakers and society at large inappropriately assumes that the stability of the planet will prevail. Scientific evidence to date strongly suggests that it is too risky to continue along this development pathway. We urgently need improved capabilities for analysing and understanding the global environmental change risks facing humanity. We assess that major improvements to an integrated model to predict the Earth system response to anthropogenic pressures is within reach, but will require a major international undertaking over the coming decade, as part of the grand challenge endeavour.

Significant improvement is needed in our ability to provide forecasts that address the full range of plausible outcomes within a probabilistic framework, that incorporate the dynamic response of both the natural and social system, and that provide results at appropriate spatial and temporal scales to assess impacts on economies, ecosystem services and human well-being. Progress in this area of research will require advances in understanding and modelling the fundamentals of physical phenomena, advances in modelling capability (including development of the ultra-high performance computing infrastructure), the incorporation of information from paleo-climate change as well as historical information on social and behavioural responses, and a more interdisciplinary framework of analysis. By meeting this challenge, models and analyses of global and regional environmental change will be able to provide direct support to governance and management at national and regional scales, and over the typical time-frames of political and management decisions.

The human consequences of global environmental change will vary across regions and within societies because of geographic differences in impacts and because of differences in the vulnerability of groups of people. An important focus of efforts to improve forecasting capability must be to better understand which groups of people are most vulnerable to global change, what threats global change poses for those communities, and the potential consequences of different adaptation and mitigation actions. These communities will experience the greatest impacts associated with global change; consequently, there is an urgent need for the scientific community to provide decision-makers and society with information that can guide action to lessen those impacts.

[4] The uncertainty on climate sensitivity alone for a doubling of CO_2 levels in the atmosphere range from 1.5 – 4^o C of average global temperature, an uncertainty range that has remained stubbornly high over the past 20 years, despite major advancements in integrating the atmosphere, stratosphere, with the hydrosphere and biosphere in global climate modeling.

Examples of key questions that need to be answered include: How will regional climate change over decadal time scales? What will be the environmental and health impact of changes to other biogeochemical cycles (e.g., nitrogen, phosphorus) or to increased loadings of toxic pollutants? How will the social, economic, and health impacts of global environmental change vary across regions and within societies? What adaptation strategies are needed to reduce vulnerability to global environmental change? When do individual human actions aggregate to cause consequences for larger regions or the Earth system? How are changes in ecosystems and biodiversity going to affect ecosystem services and human well-being? What trade-offs occur among services and human well-being, and are there strategies to minimize the adverse consequences of such trade-offs? What kinds and levels of biodiversity are needed to buffer the impacts of environmental change on ecosystem services?

Challenge 2. Observing: Develop, enhance and integrate the observation systems needed to manage global and regional environmental change.

Priority Research Questions

2.1. What do we need to observe in coupled social-environmental systems, and at what scales, in order to respond to, adapt to, and influence global change?

2.2. What are the characteristics of an adequate system for observing and communicating this information?

Major investments are being made to build more effective global and regional monitoring systems and to ensure their international coordination (e.g., through arrangements like the Global Earth Observation System of Systems). But these systems, which provide a firm foundation, still fall well short of what is needed. The current supply of information needed to manage the social-environmental system, especially at a global scale, as well as the system for delivering that information to decision-makers, is inadequate for the task. Further advances in theories, models, scenarios, projections, simulations, or compelling narratives used to understand the coupled social-environmental system and to forecast changes are constrained by limited availability of data needed to set parameters and validate predictions. Moreover, the paucity of empirical data on changes in social-environmental systems undermines the ability of decision-makers and the public to establish appropriate responses to emerging threats and to address the needs of vulnerable groups of people.

To meet any of the grand challenges, a robust data and information system is needed that can combine data and knowledge gathered over centuries with new observations and modelling results to provide a range of integrated, interdisciplinary datasets, indicators, visualizations, scenarios, and other information products. Ensuring wide access to both past and future data, especially with regard to societal dimensions, is a key challenge that cannot be taken for granted.

The observation, data preservation, and information systems required need to encompass both natural and social features, be of high enough resolution to detect systematic change, assess vulnerability and resilience, include multiple sources of information (quantitative, qualitative and narrative data and historical records), provide information about both direct drivers of change and indirect drivers, involve multiple stakeholders in the research process, support effective decisions at global to local scales, be formally part of adaptive decision making processes, provide full and open access to data, and be cost effective. They would include critical data needs such as comprehensive time-series information on changes in: (1) land cover and land use, biotic systems, air quality, climate, and the oceans; (2) spatial patterns and changes in freshwater quantity and quality, for both ground- and surface-water; (3) stocks, flows and economic values of ecosystem services; (4) trends in perceived and real components of human well-being (particularly those not traditionally measured, such as access to natural products that are not marketed); (5) socio-economic indicators, including population distribution, economic activities and mobility; (6) patterns of human responses to these developments including changes in policies, technologies, behaviours and practices, and (7) empirical measures of the efficiency of responses. The design of such a system would need to address the question of how local and regional changes can be scaled accurately and effectively to enhance the assessment of global changes, and vice-versa. The entire design should include a process and institutional arrangements for observation systems to be aligned with assessment and policy processes.

This grand challenge is both a research challenge and a challenge for science policy. Fundamental scientific questions need to be addressed in the design of cost-effective systems that can meet the needs of managers and decision-makers. The implementation of such systems, on the other hand, is not a research challenge but will nevertheless require an ongoing and concerted effort by the scientific community if it is to be achieved, even beyond the timescale of the work envisaged here.

Challenge 3. Confining: Determine how to anticipate, avoid and manage disruptive global environmental change.

<u>**Priority Research Questions**</u>

3.1. Which aspects of the coupled social-environmental system pose significant risks of positive feedback with harmful consequences?

3.2. How can we identify, analyze and track our proximity to thresholds and discontinuities in coupled social-environmental systems? When can thresholds not be determined?

3.3. What strategies for avoidance, adaptation and transformation are effective for coping with abrupt changes, including massive cascading environmental shocks?

3.4. How can improved scientific knowledge of the risks of global change and options for response most effectively catalyze and support appropriate actions by citizens and decision-makers?

It is increasingly likely that human interference will trigger highly nonlinear changes in the global environment. Such changes may be abrupt or slow, but in all cases they tend to alter the very character of the life-support system in question and to be largely irreversible on human time-scales. Examples are major shifts in regional climate, rapid collapse of ice sheets, methane release associated with thawing permafrost and warming oceans, and discontinuous transitions in the structure and functioning of biological systems. In turn, disruptive changes in social systems can result from such events, as well as from more gradual environmental changes such when reduced precipitation or degrading soil fertility eventually leads to the creation of environmental refugees. Moreover, an increasingly interconnected world generates linked trends and shocks in seemingly disparate sectors such as energy, finance, food, health, water and security. Public policies and social and economic institutions are rarely designed with such human-induced disproportional changes and regime shifts in mind.

An urgent research challenge is to understand the underlying non-linear dynamics. This will require, in particular, the future integration of environmental and complexity science, two fields that until now have developed largely separately. In order to confine global change to tolerable domains we will have to identify and track our proximity to planetary boundaries (like critical levels of ocean acidification) and in order to confine the impacts of unavoidable excursions into dangerous systems territory we will have to find optimal ways for enhancing resilience to disruptive change. A major focus of research must also be to better determine strategies for avoidance, adaptation or transformation of social-environmental systems to accommodate changes that are dangerous because of their speed, scale, non-linear nature, cumulative impact, self-amplifying nature or irreversibility.[5] Such research can also inform steps that societies should take to increase their resilience to natural and human induced disasters.

Research into appropriate response and adaptation strategies must extend beyond considerations of 'optimal' approaches to advance understanding of the political and social dynamics of responses. For example, despite the best efforts of analysts to identify optimal policies that might prevent a crisis, it is not uncommon for policies to be changed only when that crisis comes to pass; what does this imply for the design and promotion of response options? And a most exciting task will be to find out whether there are positive social tipping points, i.e., pioneering action that can tip economic machineries or social dynamics into sustainable regimes.

Challenge 4. Responding: Determine what institutional, economic and behavioural changes can enable effective steps toward global sustainability.

Priority Research Questions

4.1. What institutions and organizational structures are effective in balancing the trade-offs inherent in social-environmental systems at and across local, regional and global scales and how can they be achieved?

4.2. What changes in economic systems would contribute most to improving global sustainability and how could they be achieved?

4.3. What changes in behaviour or lifestyle, if adopted by multiple societies, would contribute most to improving global sustainability and how could they be achieved?

4.4. How can institutional arrangements prioritize and mobilize resources to alleviate poverty, address social injustice and meet development needs under rapidly changing and diverse local environmental conditions and growing pressures on the global environment?

[5] These are not the only types of dangerous global changes. For example, relatively linear but small changes in the global environment can have dangerous impacts on people if they occur over long time periods. Grand Challenges #1 and #4 are well suited to addressing impacts such as these. Grand Challenge #3 addresses the risk of more discontinuous or abrupt change.

4.5. How can the need to curb global environmental change be integrated with the demands of other inter-connected global policy challenges, particularly those related to poverty, conflict, justice and human security?

4.6. How can effective, legitimate, accountable and just collective environmental solutions be mobilized at multiple scales? What is needed to catalyze the adoption of appropriate institutional, economic, or behavioural changes?

Global change exposes gaps in social institutions, including governance and economic systems, for managing emerging global (and local) problems. The time and spatial scales of global change differ fundamentally from the types of problems that humanity has addressed in the past. Currently, decision-makers have incentives that favour short-term and private benefits, rather than long-term and collective benefits. Addressing the problems of global change, including unsustainable resource use, pollution of the global commons, growing resource demand resulting from increased population growth and per capita consumption, increased distrust by citizens of each other and their officials, and growing poverty, will require a step change in research addressing fundamental questions of governance, economic systems and behaviour.

An effective response to global change will also require much greater understanding of the inter-relations between global environmental change, global poverty and development needs, and global justice and security. For example, how will global environmental change influence progress toward the goals of preventing and eradicating poverty and hunger and improving human health? How does global environmental change shift the agenda for sustainable development in the world?

Determining how to achieve changes in social organizations, institutional arrangements and human behaviour is just as important as establishing what changes are desirable. In many cases, successful changes in institutions will stem from steps taken to achieve collective social action in response to the challenge. How can timely actions be undertaken at unprecedented and multiple geographical and geopolitical scales, where the nature and scale of the issues involved means that the actors have widely differing – and disconnected – values, ethics, emotions, spiritual beliefs, levels of trust, interests, and power? How can we better understand the role of individual decisions within diverse settings as the building block of societal decisions? How can we better understand the factors shaping individual behaviour, values and perceptions of threats and risks and how those values and perceptions influence both individual action in relation to global change and the potential for collective action? Recognizing individuals, not just policymakers, as a fundamental unit forces attention to a new level of detail on how information about the environment and feedback on thresholds being reached and breached can impact social changes and actions. Such information can influence individuals, who then incorporate this information along with other factors such as institutions or policies, to make decisions that then aggregate to impact society and the environment.

Challenge 5. Innovating: Encourage innovation (coupled with sound mechanisms for evaluation) in developing technological, policy, and social responses to achieve global sustainability.

Priority Research Questions

5.1. What incentives are needed to strengthen systems for technology, policy and institutional innovation to respond to global environmental change and what good models exist?

5.2. How can pressing needs for innovation and evaluation be met in the following key sectors?

- **a. How can global energy security be provided entirely by sources that are renewable and that have neutral impacts on other aspects of global sustainability, and in what time frame?**
- **b. How can competing demands for scarce land and water be met over the next half century while dramatically reducing land-use greenhouse gas emissions, protecting biodiversity, and maintaining or enhancing other ecosystem services?**
- **c. How can ecosystem services meet the needs for improving the lives of the world's poorest peoples and those of developing regions (such as safe drinking water and waste disposal, food security and increased energy use) within a framework of global sustainability?**
- **d. What changes in communication patterns are needed to increase feedback and learning processes to increase the capacity of citizens and officials, as well as to provide rapid and effective feedback to scientists regarding the applicability and reliability of broad findings and theoretical insights to what is observed in the field?**
- **e. What are the potentials and risks of geo-engineering strategies to address climate change, and what local to global institutional arrangements would be needed to oversee them, if implemented?**

Unprecedented challenges require novel and rapid, innovative responses. While many of these grand challenges address the need for solutions-oriented research, it is increasingly clear that the scale and potential impact of global environmental change may necessitate the consideration of entirely novel technologies, institutions and policies at multiple levels.

A number of issues demand particular research attention in this regard. First, it is clear that fundamental changes are needed in our systems of energy production and use in order to avoid dangerous climate change. Research is needed to help identify and develop new systems for energy production, metering and use and to assess the impacts of these systems on the environment and society.

Second, at current rates of growth in agricultural yield and improvements in water use efficiency, it will be extremely difficult to simultaneously meet the needs over the next half century for: a) increased food demand from growing (and wealthier) populations; b) increased human demand for freshwater for agricultural and urban uses; c) reduced greenhouse gas emissions associated with land use change and agricultural production; d) potential increased production of biofuels; e) reduced rates of biodiversity and forest loss; and, f) enhanced ecosystem services. What are plausible scenarios for addressing this problem? What are the costs, benefits, and risks of different policy, technological or ecosystem-based management strategies that might be applied?

Third, solving the problem of poverty is integral to solving the problems of global environmental change: one is as important as the other since the two issues are tightly coupled. The poor will experience the greatest harm from global environmental change. It is imperative that solutions to the problem of global change simultaneously contribute to the needs for preventing and eradicating poverty and vice versa.

Fourth, in order to rapidly address the challenges of global environmental change, we must greatly enhance our capacity for learning and this in turn requires much more effective feedback loops at multiple scales. One factor that exacerbates the challenge of dealing with global environmental change is that the time scale of human impacts on the global environment (years to centuries) does not provide the immediate feedback that could inform the public and decision-makers. Mechanisms for providing feedback between the slow variables of global change and the fast variables of human response must be developed. Better communication and feedback is also needed that can enable more rapid uptake of solutions and learning across communities and societies. And the scientific community itself needs to develop better means of learning about the applicability of research findings to real-world situations.

Finally, considerable work is underway to explore innovative approaches such as geo-engineering and green energy technologies. How can such innovation be responsibly intensified? How can risks associated with global environmental management be adequately assessed? Although research is needed to explore the entire set of policy, institutional and behavioural changes that could mitigate climate change and enhance adaptation to climate change, increased attention should now be given to research to understand the costs, benefits, and risks of various geoengineering strategies and the institutional arrangements that would be needed to oversee and assess such strategies if they were implemented.

Expected Deliverables

The primary product of the research that will be guided by these grand challenges is the knowledge base needed to support efforts to achieve sustainable development in the context of global environmental change. This knowledge base, and the process of developing it, should make a major contribution to efforts to reduce global poverty and improve global justice in ways that do not unduly exacerbating environmental stresses. The research will also yield a set of more tangible products:

- Improved regional and sub-regional information concerning potential consequences of global and regional environmental change and the likely impacts of different actions to mitigate or adapt to those changes. (Challenge 1 and 2)
- Improved accuracy of regional and subregional forecasts of climate, food security, health and environmental risks, and water availability. (Challenge 1 and 2)
- Improved information on the consequences, costs, benefits and risks of potential mitigation and adaptation strategies. (Challenge 1 and 2)

- Prioritized needs for Earth system observations of geophysical, chemical, biological and social variables and the design features of a system for delivering that information. (Challenge 2)

- A framework for forecasting the likelihood, location, drivers, severity and risk of high magnitude, abrupt or non-linear changes associated with global change. (Challenge 3)

- Options for practices and institutions that allow effective action (or provide sufficient resilience) in response to signals of impending dangerous changes. (Challenge 3 and 4)

- Designs for institutions, procedures and practices that will serve to align disconnected interests, take power asymmetries into account, and facilitate collective action. (Challenge 4 and 5)

- Options for policies and practices that accelerate social and technological innovation relevant to the needs of managing global environmental change. (Challenge 5)

- Methods for exploring the costs, benefits and risks of alternative strategies to achieve global sustainability. (Challenge 5)

- New methods for doing research (involving innovation in synthetic research approaches, participatory practices, and collaborations) and communicating results, in which stakeholders are empowered, informed and motivated through the research process to take effective action. (All Challenges)

- Enhanced capacity to undertake interdisciplinary and transdisciplinary research, including the development of a new generation of scholars taking a systems approach to challenges of global sustainability. (All Challenges)

Call to Action

This document is the product of an agenda-setting consultation that is intended to guide and stimulate scientific research on global change and global sustainability starting promptly and continuing over the next decade. As such, it is a 'living document' that will be improved and revised as more stakeholders contribute to its content and confirm its basic premises. As the agenda-setting process goes forward, the need for input from the larger community will not be limited to responding to the specific research questions, but will also necessitate innovative approaches, including reflection upon and possible changes to the decision making process within scientific institutions in order to better facilitate the interdisciplinary and transdisciplinary research that is needed.

Major progress in addressing the grand challenges and research priorities laid out here can be achieved over the next decade, but not without changes in the existing international research structures to promote interdisciplinary research, also across scientific fields, to enable greater regionalization of that research, and to allow effective interaction with decision makers and other stakeholders to both guide the research questions and deliver the research results. And, the progress cannot be achieved without enhanced resources – the scope of research needed is far broader and the nature of research organisation far more inclusive than the work carried out over the past two decades.

A major commitment will thus be required by both the institutions carrying out research and the institutions supporting that research. This document is intended to help to catalyze and guide an unprecedented decade of solution-oriented focused and intensive research. Over the next year, those who have participated in this effort will seek to build a coalition of scientists, scientific institutions, and funding agencies that will commit themselves to working together systematically – across disciplines and geographic regions – on agreed priority research questions that are critical to the sustainability of our planet for the future. The collaboration will likely be transformative for all involved, and one in which the goals are recognized as going far beyond science itself.

Appendix 1. Background on ICSU and the international global environmental change research initiatives

Thirty years after the creation of the first global environmental change programme, there is a realization that the planet is in a 'no-analogue' state. While there has been much progress on understanding the complexity and vulnerability of the Earth system, there is the growing recognition science is urgently needed to address how complex social-ecological interactions play out across scales—impacting conditions for all humankind. Scientific findings have shown that the Earth's environment is changing on all scales, from local to global, in large measure due to human activities. Much of the substantiating evidence has come from scientists who are active in the global environmental change programmes: DIVERSITAS (an international programme of biodiversity science), International Geosphere-Biosphere Programme (IGBP), International Human Dimensions Programme on Global Environmental Change (IHDP), and World Climate Research Programme (WCRP).[6] ICSU is the only common sponsor of these four programmes and has a long tradition in the field of global environmental change research.[7] In 2001, the four global environmental change programmes have come together under the banner of the Earth System Science Partnership (ESSP), which promotes international and interdisciplinary research in special focal areas (carbon, food, water and health). The four programmes and ESSP are recognized leaders in the planning and coordination of international global environmental change research (*Science*, 14 March 2008).

Recent reviews of the ESSP, IGBP, WCRP and IHDP have cited their critical contributions to international research as well as to assessments and policy initiatives, particularly in the areas of climate and biodiversity. These reviews, which were done jointly with the relevant scientific cosponsors, consistently pointed to the need to engage the scientific community to explore options and propose steps to implement a holistic strategy for global sustainability research, which would both encourage scientific innovation and address policy needs. The visioning global substantiality research process, which has produced this Grand Challenges in Global Sustainability Research document, emanated from these reviews.

In cooperation with ISSC and other partners, ICSU is leading a broad consultative process to address the decision from the ICSU General Assembly (October 2008) to outline options for an overall

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[6] The scope of this appendix is restricted to institutions and organizations sponsored or co-sponsored by ICSU. These are by no means the only organizations carrying out and coordinating research and monitoring relevant to global sustainability. That broader set of institutions will play critical roles in carrying out the type of research described in this document.

[7] In 1979, ICSU co-sponsored the first World Climate Conference, which led to the establishment in 1980 of the WCRP with the World Meteorological Organization (WMO); in 1993 the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) also became a co-sponsor. Based on the studies of the Scientific Committee on Problems of the Environment in the 1970s and early 1980s, the Council initiated the planning of the IGBP in 1986. The International Human Dimensions Programme on Global Environmental Change (IHDP) was established with the International Social Science Council (ISSC) in 1996, and the United Nations University UNU became a co-sponsor in 2007. DIVERSITAS was initially established in 1991 by the International Union of Biological Sciences (IUBS), SCOPE, and UNESCO. In 1996, ICSU joined as a co-sponsor. DIVERSITAS was initially established in 1991 by the International Union of Biological Sciences (IUBS), SCOPE, and UNESCO; in 1996, ICSU joined as a co-sponsor.

framework for Earth system research. The process will have three steps, and is founded on the principle that form should follow function:

1) a consultation primarily with, but not limited to, the scientific community to envision a research strategy and priorities for the next decade (2009);
2) a consultation on the institutional framework needed to deliver the scientific vision that results from Step 1 (June 2010). Invitees to this meeting include the co-sponsors of the GEC programmes and UNEP, as well as funders and key figures from within and outside of the programmes. Prior to this meeting there will be public Open Forum;
3) development of a plan to guide the transition from existing structures to the needed structure (2011).

ICSU has entered into this visioning process with no pre-conceived conclusions, and the ultimate goal is to strengthen, galvanize, and focus the entire sustainability research community on the most pressing societal issues.

Appendix II. Definitions

Coupled social-environment system: A system in which the social and biophysical subsystems are intertwined so that the system's condition and responses to external forcing are based on the synergy of the two subsystems.

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

Ecosystem services: The benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth.

Food security: the state achieved when food systems operate such that all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life.

Global change: Changes in biophysical environment caused naturally or caused (or strongly influenced) by human activities and the associated changes in society, institutions and human well-being. These may either manifest at the global scale or be occurring on a local scale but so widespread as to be a global phenomenon.

Global environmental change: Changes in biophysical environment caused naturally or caused (or strongly influenced) by human activities. These may either manifest at the global scale (e.g. increasing atmospheric CO_2) or be occurring on a local scale but so widespread as to be a global phenomenon (e.g. soil degradation).

Human well-being: A context- and situation-dependent state, comprising basic material for a good life, freedom and choice, health and bodily well-being, equitable and trusting social relations, security, peace of mind, and spiritual experience.

Interdisciplinary: Research that involves several unrelated academic disciplines in a way that forces them to cross subject boundaries to create new knowledge and theory and solve a common research goal.

Sustainability: A characteristic or state whereby the needs of the present and local population can be met without compromising the ability of future generations or populations in other locations to meet their needs.

Systems approach: A research approach that views individual elements as parts of an overall system and assumes that the component parts of a system can best be understood in the context of relationships with each other rather than in isolation.

Resilience: The level of disturbance that an ecosystem can undergo without crossing a threshold to a situation with different structure or outputs. Resilience depends on ecological dynamics as well as the organizational and institutional capacity to understand, manage, and respond to these dynamics.

Transdisciplinary: Research that both integrates academic researchers from different unrelated disciplines and non-academic participants, such as policymakers and the public, to research a common goal and create new knowledge and theory.

Vulnerability: Exposure to contingencies and stress, and the difficulty in coping with them.

Summary of the Sponsors Meeting on
Visioning Institutional Frameworks for Global Sustainability

UNESCO Headquarters
Paris, France
23-24 June 2010

The document *Grand Challenges for Global Sustainability Research* (ICSU-ISSC, 2010: http://www.icsu-visioning.org/) defines five major research challenges for the next decade and emphasises the need for an integrated, trans-disciplinary approach to address these. In brief, these challenges are concerned with 1) Forecasting, 2) Observations, 3) Thresholds, 4) Responses, and 5) Innovation. This sponsor's meeting was designed to examine the institutional frameworks that will be necessary at the global level to address these grand challenges. Around 40 people attended the meeting and contributed with their views on on what would be the most suitable institutional framework to support this research agenda. The annex at the end of this summary provides a complete list of the participants who represent co-sponsors of the four global environmental change (GEC) programmes (IGBP, WCRP, DIVERSITAS, IHDP and their partnetship ESSP) and the three global observing systems (GCOS, GTOS, GOOS), chairs of the scientific committees for these programmes, representatives of other related international programmes, research funding agencies, and international experts on related research and organisational structures. The meeting was chaired by Johan Rockström, with support from an expert ICSU visioning task team. The primary goal of the discussions was to agree on the essential elements of an Institutional Framework for implementing the Grand Challenges in Global Sustainability Research. The discussions were informed by a prior online consultation and an Open Forum on 22 June which had brought to together over 100 experts to adreess both the *Grand Challenges* document and the institutional framework.

The sponsor's meeting was organised as a workshop and included both plenary and break-out group discussions. The following consensus conclusions reflect these discussions.

<u>On the Grand Challenges:</u>

- The (further revised) *Grand Challenges for Global Sustainability Research* document is a an acceptable Framework for organising sustainability (or integrated Earth Systems) research over the next decade.
- The Grand Challenges document is attractive in that not only does it integrate research but it also provides a link with integrated services, eg for climate and adaptation.
- A more detailed implementation plan with more specific project criteria and/or research priorities at the programme level now needs to be developed.

<u>On institutional structures:</u>

- The *status quo* cannot deliver the integrated research that is needed to effectively respond to the Grand Challenges.

- The existing GEC programmes have performed very well, but are now variously struggling to attract funding and young researchers.
- The Earth System Science Partnership (ESSP) does not have the resources or the authority to play a lead role in responding to the Grand Challenges. Any evolution of ESSP, or development of a new overarching structure, needs to have both of these.
- Increased resources are essential to make (existing and/or) new structures work.
- The current complex system of global structures, with multiple interlocuters, makes it difficult to co-design with funders and other key stakeholders.
- There is considerable potential for greater 'core' integration of the existing programmes, eg IGBP and IHDP.
- A complete merger of all the programmes is not feasible at this stage.
- A more systematic SWOT (Strength Weakness Opportunity Threat))/gap analysis of the current programmes, joint projects and other international initiatives, eg GCOS and GEOSS, relative to the Grand Challenges would help in defining redundancies and unmet needs.
- Much integrated research in line with the grand challenges is already happening in institutions and networks outwith the GEC programmes and ESSP and this will continue regardless of whether the structures change. However, this opportunistic approach does not constitute the concerted coordinated global effort that is really necessary. Part of the research efforts in many countries will remain poorly connected in the absence of an agreed global agenda.
- Experts caution that there is a window of opportunity and momentum <u>now</u> that has been built during the development of the Grand Challenges and this must not be lost in prolonged discussion about structures. Prompt action is desirable.
- In the end, what matters is delivering the science to answer the Grand Challenges and to do this more rapidly and effectively than is likely to happen with the current structures.

The way forward

Based on the general consensus on key issues summarised in the bullets above, the first steps towards developing a new institutional framework can be proposed.

- There is a need for a new structure which allows more integration of the existing GEC structures and activities. This might be envisaged as a transformed and strengthened ESSP.
- The Grand Challenge agenda should be owned by the new structure and an overarching governance/steering committee should be set-up rapidly to guide the implementation of the transformation,
- The overarching steering committee should have the following tasks:
  1) Scientific leadership and coordination of a major new integrated research program emanating from the Grand Challenge doc (the Global Sustainability Research Program, GSRP flagship),
  2) Co-design and coordination with international funding agencies,
  3) Co-design with partners

[A potential role for the Steering Body in overall strategic planning for ICSU global environmental change research was also discussed.]

- In order to achieve these tasks, the steering committee will need dedicated secretariat support and resources, which might be co-opted from some of the existing GEC programmes and ESSP

As mentioned above a number of participants focused on the lack of evidence regarding the conduct of a systematic gap analysis or SWOT analysis during the course of the visioning process.

There was also a sense that specific and concrete action plans, using the five challenges as a framework, need to be developed to provide a sufficiently inspirational vision to capture the interest of leading scientists and galvanize them into a ten-year commitment to a coordinated research effort. In this regard, the organisational model and success of the recent International Polar Year was noted. The participants noticed an excellent opportunity to formally launch this 10 year inititative during the 2012 Open Science Conference being planned by the Global Change community.

The importance of identifying a few "flagship initiatives" that can galvanize the scientific community to work together constructively to achieve a fairly well-defined goal with a fixed timeline is also emphasized. The Appollo Project metaphor is probably not a good one. But the idea of a focused and goal-directed effort in which we all join forces is crutial to the future development.

Furthermore, several participants argued that any new initiatives should as much as is feasible: 1) be targeted towards the development of operational, integrated, and end to end environmental services delivery systems, and 2) be managed in partnerships with those institutions, such as WMO (and a number of others), that ensure the appropriate operational international coordination between these service providers, and linkages with the stakeholders and less developed countries.

The steering Committee should take up these points and work closely with the existing structures, experts, sponsors, as well as the funders and other stakeholders to guide the transformation.

Annex: Participant list of the Sponsors Meeting

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Earth System Science for Global Sustainability (ESSGS): A New 10-Year Research Initiative

Draft Concept Paper for Discussion
15 October 2010

The pace and magnitude of human-induced global change is currently beyond human control and is manifest in increasingly dangerous threats to human societies and human well-being. Decision-makers and citizens have an urgent need for knowledge and solutions that will enable effective responses to these threats and that will provide the basis for achieving sustainable development goals. The sheer scale of threats and needs mean that depending on opportunistic and ad hoc measures alone will not suffice.

Therefore, just as the scientific community established the global environmental change (GEC) research programmes 30 years ago in a revolutionary effort to further our grasp of the earth system, ICSU, ISSC and partners now propose an effort that is no less revolutionary: an innovative 10-year Research Initiative on Earth System Science for Global Sustainability (ESSGS), structured as a cutting-edge network encompassing the best of all relevant scientific disciplines, and which is highly integrative, flexible and responsive.

The goals of the Initiative are to:

- Deliver at global and regional scales the knowledge that societies need to effectively respond to global change while meeting economic and social goals;
- Coordinate and focus international scientific research to address the "Grand Challenges in Global Sustainability;"[1]
- Engage a new generation of researchers in the social, economic, natural, health, and engineering sciences in global sustainability research.

Many building blocks would come from the existing GEC landscape; but they will need to be organized in fundamentally new ways to address new research priorities. The Initiative will inspire and enlist the best researchers, be they anthropologists or geophysicists, northern or

[1] There are five interlinked Grand Challenges in all: 1. Forecasting, 2. Observing, 3. Confining, 4. Responding, and 5. Innovating.

southern, young or veteran. And it will mobilize diverse teams quickly and strategically to tackle emerging challenges and deliver solutions at the local, regional and global scale.

Why a New Initiative?

The establishment of the global environmental change research programmes thirty years ago represented a revolutionary response by the scientific community to the need for international coordination of research in order to understand the functioning of the earth system. The Initiative proposed here is no less revolutionary. The scientific community must now deliver the knowledge that will enable countries to meet needs for sustainable development, poverty alleviation and environmental protection in the face of global change. While deepening our understanding of the earth system and of human impacts, the scientific community must now build the capacity to deliver solutions to pressing sustainability challenges at regional scales. It must attract the brightest young scientists, particularly in developing countries, to tackle compelling challenges associated with global sustainability. It must significantly expand the involvement of social scientists and economists in the grand challenge research agenda. It must increasingly adopt research approaches that actively involve stakeholders and decision-makers in the process of defining and carrying out research. And it must effectively deliver end-to-end environmental services.

This past June, when ICSU convened a two-day meeting with the GEC programme sponsors, funders and other key parties, visions for the future shape of global sustainability research sometimes varied. Yet one sentiment united the room: ***business as usual is not an option.*** Current global research arrangements are unable to adequately meet these needs. They do not address the full range of global sustainability research challenges, particularly with regards to research on policy, institutional and behavioral responses to global change. They do not adequately address the needs for regional and decadal prediction of global change; or include a sufficient focus on social science, economic, and transdisciplinary research. And, they do not adequately engage younger scientists or take full advantage of the potential of networked organizational arrangements.

Initiative Characteristics

The Initiative will have the following core characteristics:

Focus on global sustainability research. The Initiative will mobilize the scientific community to deliver the knowledge that societies need at global and regional scales to effectively respond to global change while meeting economic and social goals. This would lead to improved integration of scientific disciplines and organizational structure.

Cutting-edge network structure. The progress that has been made on global change research over the last three decades was due in no small part to the effective use of coordinated research networks. In these “first generation” networks, relatively small coordinating secretariats, guided by scientific steering committees, served to identify research priorities and facilitate the involvement of scientists and the support of national and regional funders for that work. This Initiative will require “second generation” research networks. Some of the features of this network would be:

- Cutting edge knowledge management system;
- Capability of identifying network-wide research priorities and fostering strategic intensity to ensure that those priorities are addressed, and the solutions delivered in a timely fashion;
- Possesses the nimbleness and flexibility to adapt as the challenges evolve;
- Built around bias for innovation at all points in the network to ensure a constant flow of new ideas and talent;
- Designed to mobilize the network to support needs of regional nodes while also mobilizing regional nodes to address global questions;
- Distributed network management and coordination arrangements.

Built around strong regional nodes. Strong regional research nodes that can more effectively identify and respond to needs and priorities of decision-makers at regional and national scales. At the same time, regional research and analysis is increasingly needed to understand Earth system functions, human impacts, and potential responses. A strong regional research presence also facilitates the involvement of younger scientists and helps to build research capacity.

Active engagement with decision-makers. Mechanisms already exist through which the global change scientific community can interact with decision-makers at the global scale. These include the Intergovernmental Panel on Climate Change and the new Intergovernmental Platform on Biodiversity and Ecosystem Services. Through these mechanisms, policy-makers are able to identify their highest priority needs and the scientific community is able to assess the state of knowledge bearing on those needs. These mechanisms also help to reveal policy relevant gaps in research and knowledge and consequently they have helped the global change research and funding community set priorities.

A critical need now exists for similar arrangements to better facilitate science-policy interactions at regional scales. Information provided at regional scales can better inform the key regional and national decisions that will ultimately determine how effective societies are in responding to global change. The Initiative will thus place significant emphasis on either utilizing existing mechanisms for science-policy interactions (e.g., in Europe) or creating new mechanisms to engage with decision-makers where such mechanisms do not exist.

Actively engage the full range of disciplines. Social sciences have long been a component of Earth system research, but tackling the grand challenges for global sustainability research requires a stronger involvement and greater integration of the social sciences, economics, health sciences, engineering and humanities, along with the natural sciences. The goal of expanding the involvement of the social sciences in global change research has been difficult to achieve. We believe that the strongly regional and networked structure of this Initiative combined with the focus on research aimed at understanding how to achieve sustainability in the context of global change will provide a transformative opportunity for more active engagement of the social sciences, economics and health sciences in particular. In designing the Initiative, we will identify active steps that could be taken to 'grow' the involvement of these disciplines in the Initiative through time.

Actively engage young scientists. The GEC research programmes have been successful over the past three decades because of the caliber of young scientists that became engaged in the programmes when they were established. These research challenges were seen as cutting edge research opportunities around which young scientists could build their careers. Based on our experience of involving young scientists in developing the Grand Challenges for Global Sustainability Research, we believe that the set of new research priorities that more directly address the sustainable development agenda provides a similar opportunity to engage the brightest young scientific talent. To succeed, the Initiative must focus on exciting research questions, must be open to "bottom up" innovation in research directions, and must proactively ensure that governance and decision-making in the Initiative actively incorporates both younger and more senior scientists.

Creating the ESSGS

Building the overarching structure

At the June 2010 meeting of sponsors, funders, GEC programme chairs and key partners, many participants shared a belief that even a reform of the existing Earth System Science Partnership (ESSP) would not be able to effectively guide the initiative. There needs to be a new, overarching structure with the authority and resources that the ESSP never had, and which would be crucial for nudging the GEC community towards a more integrated research.

It is proposed to create a new Steering Committee whose tasks are to oversee the creation of the initiative, and take the lead on the initiative's vision, strategy, fund-raising, and relationships with partners and stakeholders, as well as to provide scientific guidance to the entire Initiative. This Committee will act as an interim governing body to the new initiative and should be appointed for 18 months to lead its creation and design, and to explore options for its future governance structure. During the 18 months, this group would decide on governance options, explore funding options, obtain the necessary 'high level' commitments from governments, and propose the final Board structure and composition. After the 18 months design period, the Committee would transition into the full board, to govern and implement the initiative. In order to ensure continuity, some of the Committee members may be asked to stay on in the new governance structure.

This Committee will have high level representation from all the main stakeholders including researchers, funders, industry, and other stakeholder groups. The membership of this Committee may look like the following:

1. *Current core programme sponsors*
   - International Council for Science (ICSU) and International Social Science Council (ISSC), and possibly other UN organizations.
2. *Research donors*
   - Representatives of the Belmont Forum and the International Forum of Research Donors (IFORD)
3. *Scientists* (6)
   - Internationally renowned scientists, including at least one early career scientist. The set of scientists will have to have a fair balance with regards to region, gender and scientific background/discipline.
   - Representation of the existing GEC programmes, e.g. via inclusion of the chair of the ESSP.
4. *Users of global sustainability information and knowledge*
   - Individuals with experience at the interface of global change research and policy. This should include people working at global, regional and national scales.
5. *Representatives of civil society and business*
   - This would include representatives from industry, NGOs, and could include other distinguished individuals (e.g., a retired government leader, etc.)

Note that current core programme sponsors may sit on the Committee in ex-officio capacity. Collectively, the set of individuals selected for the Steering Committee (and ultimately for the governing Board) would provide outstanding substantive guidance and bring a set of relationships that could be mobilized in support of the initiative. More specifically, the set of individuals would meet the following criteria:

- World renowned scientific leaders.

- Among the non-scientists, individuals with a strong affinity with science and with the potential use of science in decision-making.
- Individuals with a strong commitment and engagement to both environmental and social concerns.
- Individuals capable of interacting and engaging across existing GEC Programmes and fora.
- Individuals with direct experience and knowledge of political decision-making around environmental issues at the highest levels.
- Individuals who can help open doors for possible core funding and research funding.
- Individuals with expertise in building and governing complex network-based institutions.
- Individuals with experience in building scientific capacities at individual, organizational and systemic levels.
- Appropriate gender and regional balance.

Integrating existing GEC programmes

Although integrated research is already happening in the GEC programmes and outside of institutions and networks contributing to the GEC programmes, these scattered efforts do not constitute a concerted, coordinated global effort. In the absence of a global agenda, research efforts in many countries continue to be left out. The Initiative will thus integrate the current GEC programmes, when necessary and feasible. While there is not yet a consensus for deep integration within the GEC community, there is strong and growing recognition that more effective integration is necessary.

Designing and Creating the Initiative

Once the Steering Committee is in place, it will oversee the development and early implementation of the Initiative. The design of a global interdisciplinary research network such as that proposed here will require an intensive design phase that must draw on the expertise of the scientists who will be involved in the research, but equally importantly must draw on the deep knowledge and expertise that now exists regarding network design and knowledge management. We anticipate the following steps:

1. Engage organizational design experts. As its first task, the Steering Committee will issue an RFP to retain a firm with extensive experience in organizational and network design to ‘staff’ the design process.

2. Initiate a Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis of existing GEC research. Using the Grand Challenges in Global Sustainability as the framework, analyze success of and gaps in the existing research activities at both global and regional scales and gaps in capacity to carry out the necessary research.

3. Explore the greater integration of GEC programmes. One possibility would be that the Steering Committee will successively replace the current ESSP when it starts. Supported by the outcomes of the SWOT analysis, it will carry out discussion with the GEC programmes regarding their integration into the new structure.

4. Assemble information on obvious regional 'nodes' for the network. Dialogs will be carried out with those institutions/organizations in order to identify a set of candidate nodes that could fill gaps in the network.

5. Explore alternative options for the governance, funding, and priority setting for the network (see Figure 1.). The Steering Committee has a life time of 18 months, after which it will be replaced with a more permanent governance structure.

6. Explore options for knowledge management systems.

7. Develop a detailed research plan for the first three years of the Initiative. Based on the Grand Challenges document, develop a much more concrete and specific action plan. As a first step in this effort, a small number of priority areas/directions must be established.

8. Co-design and coordinate an implementation plan. An open call should be issued to scientific community including those who are currently engaged in GEC research and those who are willing and able to contribute to the needs of the action plan. This includes the identification of organizations/institutions that will be responsible for components of the research, the funding needed, and the outputs anticipated.

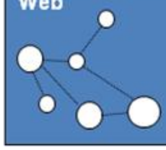
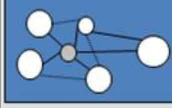
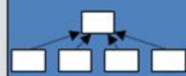
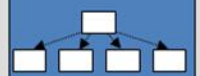
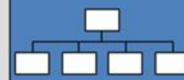
9. Develop a formal relationship among the relevant network nodes that will be promoting and/or carrying out the research and a funding plan for those nodes and for the Initiative management.

10. Reach out to potential partners and user. As an example, the UN High Level Panel on Global Sustainability would be one of such groups.

Launching the Initiative

The 2012 "Planet Under Pressure" conference would provide a useful opportunity to launch the initiative.

Figure 1. Network Design Models (Source: McKinsey & Co.)

	Web	Enabled network	Loose federation	Tight federation	Single org
					
Governance	• No joint governance	• Minimal joint governance	• Limited joint governance, limited if any shared services	• Strong shared governance, and targeted shared services	• Single entity, centralized governance and decision making
Shared processes & infrastructure	• Ad hoc knowledge and resource sharing	• Facilitated knowledge exchange and collaboration on selected issues	• Some shared infrastructure; facilitated knowledge exchange	• Significant shared infrastructure and knowledge sharing	• Majority of processes & infrastructure are shared
Role of the center	• N/A – no core • Complete autonomy of independent organizations	• Center or "lead node" facilitates collaboration among autonomous organizations	• Center coordinates key issues on behest of field • Strong local autonomy	• Center facilitates high level strategic policy • Local flexibility in delivery	• Center leads/ supports strategy development (with input from field)
Examples	• Linux	• Global Fund • ICBL • WWF	• GAVI • Visa (pre-reorg)	• Amnesty International	• CI • Ashoka

Belmont Forum Water Resources and Water Security

Near-term activity:

Belmont Forum co-alignment with NSF's Water Sustainability and Climate (WSC) program:

- The GOAL of WSC is to understand and predict the interactions between the water system and climate change, land use (including agriculture), the built environment, and ecosystem function and services through place-based research and integrative models.
- Critical criterion: projects must be truly interdisciplinary rather than multi-disciplinary, with social science as a key component
- Studies of the water system using models and/or observations at specific sites singly or in combination that allow for spatial and temporal extrapolation to other regions, as well as integration across the different processes.
- FY10 awards (totaling $25M) were a combination of exploratory, incubation projects and full projects that involved either (1) new observations and model development or (2) synthesis projects which will employ existing data
- The next solicitation will be issued in FY11 (FY13) and awards to be made in FY12 (FY14).

Longer-term Vision:

Through WSC and co-aligned efforts, and new complementary activities, develop calibrated models that can address a range of coupled climate-hydrologic processes that can be adapted by appropriate organizations for use in developing countries.

Belmont Challenge

Australian Efforts to Develop Information to Guide Coastal Adaptation

Many coastal regions are already experiencing the effects of relative (local) sea level rise from a combination of factors. Into the coming decades, coastal areas will be exposed to increasing risks due to sea level rise and climate change. Exacerbating the risk is the increasing human pressures on coastal areas – location of settlements, increasing intensity of infrastructure and modification of shorelines.

There is significant regional diversity in how coastal areas will respond to a changing climate. Populated deltas, especially the Asian mega deltas, low lying coastal urban areas and atolls have been identified as key global hotspots.

We are at a turning point in developing the systems and modelling capacity to key turning point in getting tools however, there are still key knowledge gaps in our ability to provide information to decision makers that can help to inform the range of adaptation options that need to be considered and the timeframes and implications of those options. Investment and collaboration in the right priorities can help to deliver this capability.

This paper provides a structure to consider the knowledge and science base required to support coastal adaptation. The state of Australia’s capability is identified against each category as an example.

1. Coastal observations and monitoring (data) Key questions: Is there adequate knowledge about the behaviour of individual system components, and can we measure rate of change? Access to reliable data on key climate parameters will underpin models of change and our understanding the climate change contribution to risk into the future. While data across a broad spectrum of parameters would be desirable there are a number of priority areas: sea level rise, wave climates, geomorphological response and coastal assets exposed to climate change impacts.			
Priority elements	**Achievements to date and near term priorities**	**Medium term priorities (over next 20 years)**	**Regional focus for investment priority**
Sea level rise	29 locations, good observations of regional sea level rise variability	Adequate global observation capacity on major ice sheets	Australia Pacific and East Timor
Wave climate including direction and energy	Instrument network of wave rider buoys (strong focus SE coast)	Need to assess adequacy of coverage and importance wave monitoring particularly in context of global linkages	Australia Pacific and East Timor
Extreme events - storms & cyclones	National storm tide data set (for cyclonic and non cyclonic coastline) Tropical cyclone database repair and review		Australia Pacific and East Timor
Geomorphological response	Nationally consistent database of coastal geomorphology (identifying erodible areas) GIS line map format (queriable) and polygon format (spatial representation) Example sites of historic shoreline change Estimates of sensitivity to change wave climate for a variety of shoreline types	Increased knowledge sand transport/ sediment budgets Bathymetry for priority areas Estuary morphology	Australia
Exposed coastal social, economic and environmental assets	Nationally consistent elevation data (mid resolution with priority areas at high resolution) working towards seamless DEM from land to ocean Dataset of exposed infrastructure (residential, road/rail, commercial and industrial) Variable datasets of environmental assets of national significance		Australia

2. Coastal analysis and prediction systems (modelling)			
Modelling global and regional climate change has traditionally focused on incremental change (change to the mean), however adaptation requires a better knowledge on the change to the extremes – as that is where the greatest risks lie and where planning needs to be implemented to manage risk. An improved understanding of high end risk of ice sheet dynamics/melt and improving predictions of hazardous weather including storm surges and cyclonic storms are key priorities. At smaller scales coupled climate and hydrological and morphodynamic modelling will be need to identify risk to coastal areas. Downscaled projections to run these models will be needed as well as the ability to consider multiple stressors and identifying thresholds of systems.			
Priority elements	**Achievements to date and near term priorities**	**Medium term priorities (over next 20 years)**	**Regional focus for investment priority**
Climate system modelling and projections:	Downscaling of modelling results at relevant resolutions	Second generation downscaling	Australia Pacific and East Timor
Sea level rise	Understanding regional sea level rise variability	Remain engaged with global effort to reduce the uncertainties around the response of the major ice-sheets to warming in order to improve estimates of timing and magnitude of global and regional sea level rise	Pacific and East Timor
Wave climate	Modelling framework developed using the south east coast of Australia as a case study	Engage through a WCRP/JCOMM supported workshop (Geneva April 2011)to to establish a coordinated framework for global wave climate projections	Australia Pacific and East Timor
Extreme events - storms & cyclones	Initial research underway to develop and test techniques for modelling likely changes in the frequency and intensity of extreme events and coincident extreme events, such as flooding and storm surge at appropriate resolution		Australia Pacific and East Timor
Coupled climate and hydrological /morphodynamic models	Initiate work: Identify likelihood and timing of breaching key thresholds/shoreline stability Modelling sediment pathways inc disturbed systems Model interaction with flooding/protective measures	Deliver capacity for integrated modelling of hydrological and geomorphic systems and in context of coincident events Modelling framework to assess coincident risks from changes in offshore wave climate, in shore storm surge and estuarine flooding	Australia

Social economic modelling	Damage curves (relationship between hazard, event and cost) Understanding of coastal responses to key management actions	Develop National Integrated Assessment modelling capability	Australia
3. Information and communication How to present information so it is useful to relevant decision makers and what decision support tools will be required.			
Priority elements	**Achievements to date and near term priorities**	**Medium term priorities (over next 20 years)**	**Regional focus for investment priority**
Scenario development	Development of storylines for different climate change scenarios for geographic regions		Australia
Identify most vulnerable coastal systems	Coastal risk assessment report identifies vulnerable areas at a national scale – (flooding and erosion for residential properties)	Second generation knowledge	Australia Pacific and East Timor
Visualisation tools to help communicate risks	Sea level rise mapping – interactive and static map formats to help communicate risk across range of coastal stakeholders	Second generation tools that build on modelling advancements	Australia
Cost and benefits of adaptation options	Early work on developing information on the costs and benefits of adaptation pathways		Australia
4. Coastal capacity building capability			
Priority elements	**Achievements to date and near term priorities**	**Medium term priorities (over next 20 years)**	**Regional focus for investment priority**
Platform for knowledge data sharing	National Elevation Data Framework web portal – facilitate discoverability and accessibility to Australian Government elevation data	Web portal extended to include state and territory elevation data Develop National Climate Services capability in line with global efforts agreed at the World Climate Conference 2009	Australia
Building capacity in developing countries to	Engagement with scientists and decision-makers to enhance sharing of knowledge and facilitate its		Pacific and East Timor

access global science/tools	incorporation in planning		

Climate Change, Agriculture and Food Security

The program on Climate Change, Agriculture and Food Security (CCAFS) is a strategic partnership of the Consultative Group on International Agricultural Research (CGIAR) and the Earth System Science Partnership (ESSP)

The Challenge for Agriculture and Food Security
Climate change is an immediate and unprecedented threat to the food security of hundreds of millions of people who depend on small-scale agriculture for their livelihoods. Climate change affects agriculture and food security, and likewise, agriculture and natural resource management affect the climate system. The complex and dynamic relationships between climate change, agriculture and food security are also shaped by economic policies, political conflict and factors such as the spread of infectious diseases. The relationships between all these factors and how they interact are not currently well-understood, nor are the advantages and disadvantages of different responses to climate change.

The Research Challenge
The next step is to integrate knowledge about climate change, agriculture, and food security. Bringing together these domains in a meaningful way requires an urgent change in the way research is planned and carried out, and the way researchers explain their findings. As no single research organisation has the ability to tackle this work by itself, CCAFS is opening new opportunities for studying these interactions.

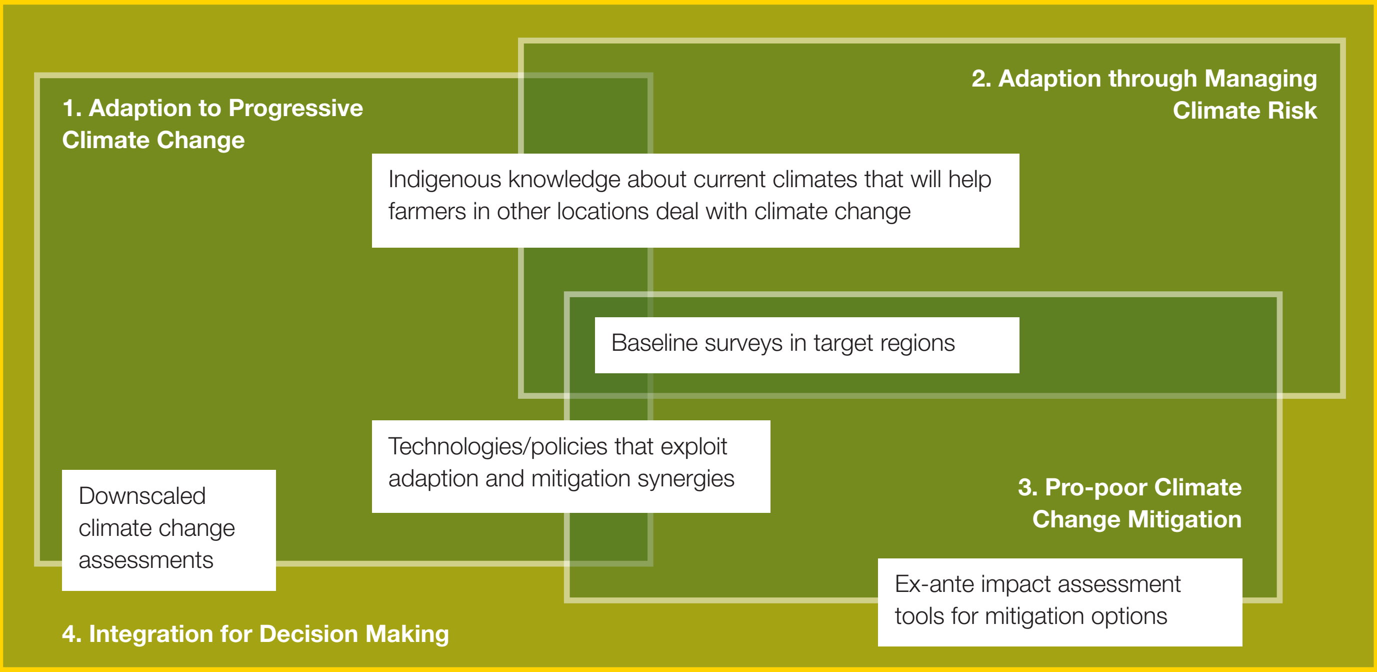
A New Way of Working
CCAFS brings together the world's best researchers in agricultural science, development research, climate science, and Earth System science, to identify and address the most important interactions, synergies and tradeoffs between climate change, agriculture and food security. CCAFS will also involve farmers, policy makers, donors and other stakeholders, to integrate their knowledge and needs into the tools and approaches that are developed. Research in CCAFS will be carried out by teams of partners with complementary skills and expertise, pairing institutions from the North and South, including South-South collaboration. These partnerships are expected to generate new ways of working, and broaden dialogue between science and policy.

Organisations leading CCAFS

Consultative Group on International Agricultural Research (CGIAR)
The CGIAR, established in 1971, is a strategic partnership of many members that support 15 international agricultural research centres. The centres collaborate with hundreds of government and civil society organisations, as well as private business around the world. Today, more than 8000 CGIAR scientists and staff work in over 100 countries.

Earth System Science Partnership (ESSP)
The ESSP was established in 2001 to promote cooperation for the integrated study of the Earth System, its changes, and the implications of these changes for global sustainability. The ESSP comprises four international research programs that specialise in different dimensions of global environmental change: biodiversity and agro-biodiversity; institutions, socioeconomics and human security; physical, chemical and biological processes; and climate science.

How CCAFS themes will work together. Some examples of joint activities/products are illustrated.



Goal and objectives

The overall goal of CCAFS is to overcome the additional threats posed by a changing climate to achieving food security, enhancing livelihoods and improving environmental management.

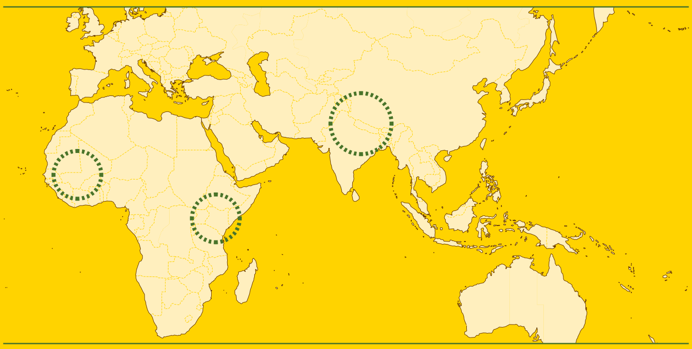
In order to meet this goal, the programme's objectives are to

- Identify and develop pro-poor adaptation and mitigation practices, technologies and policies for agriculture and food systems.
- Support the inclusion of agriculture in climate change policies, and of climate issues in agricultural policies, at all levels.

Research themes

1. Adaptation to Progressive Climate Change
2. Adaptation through Managing Climate Risk
3. Pro-poor Climate Change Mitigation
4. Integration for Decision Making

Where CCAFS works



In 2011, CCAFS will focus on three regions: the Indo-Gangetic Plains, and West and East Africa. These regions were chosen to represent areas that are becoming both drier and wetter, and because they will generate results that can be applied and adapted in other regions worldwide as the program evolves.

How CCAFS will make a difference

Promoting more adaptable and resilient agriculture and food systems, leading to better food security, better livelihoods, and better environmental management.

Mainstreaming climate variability and climate change issues into national, regional and international development strategies and institutional agendas.

Enhancing peoples' understanding of climate change issues, including the tradeoffs between food security, livelihoods and the environment, as well as measures for adapting to and mitigating climate change.

Informing actions to deal with climate change, and ensuring that decisions on policies and actions are based on the best information and data

More resilient rural communities, in a better position to adapt to a changing climate and increase food security, while taking into account sustained livelihoods and the environment

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NORDIC ECOLABEL
541-309
Printed matter

Agriculture, Food Security and Climate Change: Outlook for Knowledge, Tools and Action

Background paper prepared for The Hague Conference on Agriculture, Food Security and Climate Change on behalf of the CGIAR by the Program on Climate Change, Agriculture and Food Security of the Consultative Group on International Agricultural Research (CGIAR) and the Earth System Science Partnership (ESSP).

Scope: This paper reviews the state of current scientific knowledge on the links between climate change, agriculture and food security, in terms of anticipating impacts, managing climate variability and risks, accelerating adaptation to progressive climate change, and mitigating greenhouse gas emissions from the agricultural sector.

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Acknowledgements: This document has been produced with the financial assistance of the European Union, Canadian International Development Agency, World Bank, USAID, New Zealand Ministry of Foreign Affairs and Trade and Danida and with the technical support of IFAD. The views expressed herein cannot be taken to reflect the official opinion of these agencies, nor the official position of the CGIAR. The authors are grateful to Peter Gardiner and Rudy Rabbinge for their comments on an earlier draft. The authors are responsible for any errors and gaps in the paper.

Summary

Agriculture and food security are key sectors for intervention under climate change. Agricultural production is highly vulnerable even to 2C (low-end) predictions for global mean temperatures in 2100, with major implications for rural poverty and for both rural and urban food security. Agriculture also presents untapped opportunities for mitigation, given the large land area under crops and rangeland, and the additional mitigation potential of aquaculture. This paper presents a summary of current scientific knowledge on the impacts of climate change on farming and food systems, and on the implications for adaptation and mitigation. Many of the trends and impacts are highly uncertain at a range of spatial and temporal scales; we need significant advances in predicting how climate variability and change will affect future food security. Despite these uncertainties, it is clear that the magnitude and rate of projected changes will require adaptation. Actions towards adaptation fall into two broad overlapping areas: (1) better management of agricultural risks associated with increasing climate variability and extreme events, for example improved climate information services and safety nets, and (2) accelerated adaptation to progressive climate change over decadal time scales, for example integrated packages of technology, agronomy and policy options for farmers and food systems. Maximization of agriculture's mitigation potential will require, among others, investments in technological innovation and agricultural intensification linked to increased efficiency of inputs, and creation of incentives and monitoring systems that are inclusive of smallholder farmers. The challenges posed by climate change to agriculture and food security require a holistic and strategic approach to linking knowledge with action. Key elements of this are greater interactions between decision-makers and researchers in all sectors, greater collaboration among climate, agriculture and food security communities, and consideration of interdependencies across whole food systems and landscapes. Food systems faced with climate change need urgent action in spite of uncertainties.

Introduction: meeting food demand in the face of climate change

Recent decades have seen global food production increasing in line with – and sometimes ahead of – demand. However, FAO projects that demand for cereals will increase by 70% by 2050, and will double in many low-income countries (FAO, 2006). Increasing demand for food is an outcome both of larger populations and higher per capita consumption among communities with growing incomes, particularly in Asia. Supply-side drivers include efficiency gains associated with vertical integration in industrial food supply chains (Reardon et al., 2004). To meet higher demand, food production is obviously of major importance. But poor households' inability to secure food through markets and non-market channels may limit food security even where food is globally abundant (Barrett, 2010). For those who rely on subsistence agriculture, food security is strongly dependent on local food availability, but for the majority who exchange cash, other commodities or labor for food, the access component is of critical importance, especially in relation to dietary diversity and nutrition. The impacts of climate change on food security therefore should consider both direct impacts on local food production and also the fuller set of interactions with the whole food system (Ericksen, 2009; Ingram, 2009; Liverman and Kapadia, 2010).

Despite considerable increase in global food production over the last few decades, the world's efforts to meet the Millennium Development Goal of reducing hunger by half by 2015 appears to be beyond reach. In fact, the number of people suffering from chronic hunger has increased from under 800 million in 1996 to over a billion according to FAO's most recent estimate in 2009 (FAO, 2009a). Most of the world's hungry are in South Asia and sub-Saharan Africa. These regions have large rural populations, widespread poverty and extensive areas of low agricultural productivity due to steadily degrading resource bases, weak markets and high climatic risks. Farmers and landless laborers dependent on rainfed agriculture are particularly vulnerable due to high seasonal variability in rainfall, and endemic poverty forcing them to avoid risks. Climate change is of particular significance for these countries, which already grapple with global and regional environmental changes (Aggarwal et al., 2004; Cook-Anderson, 2009; Toulmin, 2009) and significant interannual variability in climate (Arndt and Bacau, 2000; Haile, 2005). For example, changes in the mean and variability of climate will affect the hydrological cycle and crop production (Easterling et al., 2007) and land degradation (Sivakumar and Ndiang'ui, 2007). In recent times, food insecurity has increased in several such regions due to competing claims for land, water, labor, and capital, leading to more pressure to improve production per unit of land. Rapid urbanization and industrialization in South Asia, for example, has taken away from agriculture some very productive lands and good quality irrigation water (see e.g. Fazal, 2000).

Agriculture is highly sensitive to climate change. Even a 2C rise in global mean temperatures by 2100, in the range of the IPCC low emissions (B1) scenario, will destabilize current farming systems (Easterling et al., 2007). Climate change has the potential to transform food production, especially the patterns and productivity of crop, livestock and fishery systems, and to reconfigure food distribution, markets and access (Nelson et al., 2009). The adaptive capacity of rural and urban communities confronted by economic and social shocks and changes is enormous, but needs ongoing, robust support (Adger et al. 2007). Climate change will bring further difficulties to millions of people for whom achieving food security is already problematic, and is perhaps humanity's most pressing challenge as we seek to nourish nine billion people by 2050 (Godfray et al., 2010).

Anticipating impacts of climate change on agriculture and food security

Projections of climate change are inherently uncertain, due to the natural variability in the climate system, imperfect ability to model the atmosphere's response to any given emissions scenario, difficulties in evaluating appropriate methods to increase the temporal and spatial resolution of outputs from relatively coarse climate models, and the range of possible future emissions (see e.g. Challinor et al., 2009a). These uncertainties are compounded by the paucity and unreliability of basic information related to agricultural production. Land-based observation and data collection systems in parts of the world have been in decline for decades. This affects the most basic data: weather data, land-use data, and crop and livestock distribution data, for example. Estimates of the cropland extent in Africa range from about 1 to more than 6 million km^2, the value depending on choice of satellite-derived product (Fritz et al., 2010). The uncertainty in such basic information as which crops are grown where, and how much of them there is, adds considerable difficulty to the quantification and evaluation of impacts and adaptation options. Another key gap is existence of data, tools and models at spatial and temporal scales appropriate to decision-making. Production impacts are often aggregated over large areas such as the country or region, and this can hide considerable heterogeneity in climatic conditions and agricultural production (Jones and Thornton, 2003). Nonetheless, as outlined below, scientific knowledge is improving, with growing certainty around major trends, and emerging approaches to improve data and tools for decision-making.

Estimating trends in impacts on farming and food systems

The potential impacts of climate change on agricultural production in different parts of the world have been assessed in numerous studies and reviewed in successive assessment reports of the IPCC (2007). Ranges for major crops depend on the region under study, the methods and models used, and the emission scenarios simulated, and, as noted above, there is considerable uncertainty about such estimates (Challinor et al., 2007). Nevertheless, most studies indicate that agriculture in the tropics is likely to be severely affected in the coming decades by climate change. Some of the key impacts on farming and food systems are noted below.

Crop yields: There has been much progress in recent years in combining climate models with crop models in order to understand and project climate impacts (see review by Challinor et al., 2009b). In spite of the inherent uncertainties, robust responses of yield to climate change have been found using both empirical (e.g. Schlenker and Roberts, 2009) and process-based crop models (e.g. Challinor and Wheeler, 2008). For example, uncertainty in rainfall is not always a factor that limits the predictability of yield; temperature may be more important in a number of cases (e.g. Thornton et al., 2009; Lobell and Burke, 2008).

Livestock: Future impacts of climate change on livestock production are likely to be both direct, for example productivity losses (physiological stress) owing to temperature increases, and indirect, for example changes in the availability, quality and prices of inputs such as fodder, energy, disease management, housing and water (Thornton, 2010).

Fish: The distribution and population sizes of marine fish species are already affected by changes in sea temperature (e.g. Perry et al., 2005). Climate change will affect all dimensions of food security of fishers due to its impact on habitats, stocks and distribution of key fish species (Cochrane et al., 2009). Projected changes in the variability and seasonality of climate will also impact aquaculture through effects on growth rates and stability of domesticated fish populations.

Biodiversity: The impacts of climate change on the structure and function of plant and animal communities are widely demonstrated for terrestrial, freshwater and marine ecosystems (Walther et al., 2002; Parmesan, 2006). Changes in species distributions, phenology and ecological interactions will have impacts, for example, on pollination, invasions of agricultural systems by weeds and locations of major marine fishing grounds.

Pests and diseases: There is growing evidence that climatic variations and change are already influencing the distribution and virulence of crop pests and diseases, but the interactions between crops, pests and pathogens are complex and poorly understood in the context of climate change (Gregory et al., 2009). New equilibria in crop-pest-pesticide interactions will be established with consequences for food security. Climate change will also have significant impacts on the emergence, spread and distribution of livestock diseases through various pathways (Baylis and Githeko, 2006).
Carbon fertilization: There is ongoing debate about the impacts of carbon fertilization on plants and yields, and how changing ozone concentrations may interact with carbon dioxide effects and with other biotic and abiotic stresses (Challinor et al., 2009b). Impacts will also be felt on grassland productivity and species composition and dynamics, resulting in changes in animal diets and possibly reduced nutrient availability for animals (Thornton et al., 2009).
Irrigation: Climate change will impact the delivery and effectiveness of irrigation (Kundzewicz et al., 2007). The predicted increase in precipitation variability, coupled with higher evapotranspiration under hotter mean temperatures, implies longer drought periods and would therefore lead to an increase in irrigation requirements, even if total precipitation during the growing season remained constant.
Food storage and distribution: Climatic fluctuations are known to affect post-harvest losses and food safety during storage, for example by causing changes in populations of aflatoxin-producing fungi (Cotty and Jaime-Garcia, 2007). It is anticipated that more frequent extreme weather events under climate change will damage infrastructure, with detrimental impacts on food storage and distribution, to which the poor will be most vulnerable (Costello et al., 2009).
Food accessibility and utilization: Nelson et al. (2009) used economic modeling to predict that prices of most cereals will rise significantly due to climatic changes leading to a fall in consumption and hence decreased calorie availability and increased child malnutrition. At the same time, there are reports indicating that the nutritional value of food, especially cereals, may also be affected by climate change (Ziska et al., 1997; Hesman 2002; Nagarajan et al. 2010). Climate change will also affect the ability of individuals to use food effectively by altering the conditions for food safety and changing the disease pressure from vector, water, and food-borne diseases (Schmidhuber and Tubiello, 2007).

Improving the knowledge system: databases and models

Technology is being brought to bear to improve the quality and accessibility of data on agriculture under climate change. Advances include better remote sensing of weather information (including prospects to backfill missing daily weather data from historical records), validation of different land-use products using Wikis and Google Earth ("cloudsourcing": see www.geo-wiki.org, for instance), and dissemination of information using mobile phone technology, to name just a few. But many of these things need to complement land-based observations, not substitute for them. A similar situation exists with respect to germplasm data; specific information on the response of crops to weather and climate is often not collected, but it could be with relatively modest additional effort.

New approaches are emerging to tailor agricultural climate-impact predictions to the needs of decision-makers at household, district and national levels. One example is the Agricultural Model Intercomparison and Improvement Project (AgMIP), based at Columbia University, a highly distributed climate-scenario simulation activity for historical model comparison and for future climate change conditions. AgMIP is being designed on the basis of the participation of multiple crop, livestock and world agricultural trade modeling groups around the world, with the goals of improving the characterization of food security due to climate change and to enhance adaptive capacity in both low-income and high-income countries. A second example is EQUIP (End-to-end Quantification of Uncertainty for Impacts Prediction, www.equip.leeds.ac.uk), a consortium project bringing the UK climate modeling, statistical modeling, and impacts communities together to work on developing risk-based prediction for decision making in the face of climate variability and change.

There are parallels between the situation for agricultural impacts modeling and the data needed to run them. Data are needed not only as input for modeling and scenario analysis, but also for characterization of food production systems in target sites, monitoring, and impact assessment, for example. There have been considerable improvements in recent years with regard to data availability. There are now large holdings of publicly available spatial and other data concerning natural resources, such as the Consortium for Spatial Information initiative of the Consultative Group for International Agricultural Research (www.cgiar-csi.org) and HarvestChoice (www.harvestchoice.org), for example. The International Household Survey Network (www.ihsn.org) is doing the same for household-level sample survey data, and is improving the availability, accessibility and quality of survey data in low-income countries, and encouraging their analysis and use. Sachs et al. (2010) recently called for a global monitoring system of agricultural practices and technologies, a database that would undoubtedly aid countries in strategically deploying the most promising technological adaptation options.

A major challenge for the research community and policy-makers is to understand not only the impacts, but also the interactions among components of the farming system (see e.g. Tubiello et al., 2007) and the food system (Ericksen, 2009). While an impact-based perspective suggests that increasing interactions results in increasing uncertainty (Challinor, 2009), we also know that adaptive strategies will, even in the absence of intervention, reduce the range of plausible futures (Morton, 2007). Farmers will do all they can to prevent negative impacts. This fact alone may help to improve prediction in the face of uncertainty as it reduces the range of possible futures. However, the extent to which adaptation will reduce uncertainty will vary according to the particular situation, so that the nature of adaptation remains one of the key uncertainties in anticipating impacts of climate change on agriculture and food security.

Modeling approaches are beginning to provide policy guidance based on linking climate models, crop models and economic implications (Lobell et al., 2008; Nelson et al., 2009). Broader frameworks could consider the interactions of different technical and policy sectors, thus addressing the issues outlined above. For example, agricultural intensification for the sole purpose of increased food production, or exclusively for climate change mitigation, will not create sustainable agricultural landscapes. Research must also support institutional learning, recognizing the potential threats that change presents to people's livelihoods, particularly those in already precarious situations. Increased institutional capacity would allow for the development of adaptation and mitigation options that go beyond sector-specific management and lead to more systemic changes in resource management and allocation.

Managing climate variability and risk

Due to the natural variability of the climate system, anthropogenic climate change will be experienced largely as shifts in the frequency and magnitude of extreme events (Karl et al., 2008). Since many of the projected impacts of climate change are amplifications of the substantial challenges that climate variability already imposes on agriculture, particularly for smallholder rainfed farming systems in the tropical and sub-tropical drylands, better managing the risks associated with climate variability provides an immediate opportunity to build resilience to future climate change. Climate shocks such as drought, flooding or heat waves lead not only to loss of life, but also long-term loss of livelihood through loss of productive assets, impaired health and destroyed infrastructure (McPeak and Barrett, 2001; Dercon, 2004; Carter et al., 2007). The uncertainty imposed by climate variability is a disincentive to investment in improved agricultural technology and market opportunities, prompting the risk-averse farmer to favor precautionary strategies that buffer against climatic extremes over activities that are more profitable on average (surveyed in Barrett et al., 2007; Hansen et al., 2010). Apart from effective intervention, projected increases in climate variability can be expected to intensify the cycle of poverty, vulnerability and dependence on external assistance. A comprehensive strategy for adapting agriculture and food systems to a changing climate must therefore exploit the range of promising strategies for managing current climate-related risk.

Seasonal forecasts for adaptive management

Interaction between the atmosphere and the oceans provides the basis for forecasting climate conditions several months in advance. Seasonal climate forecasts, in principle, provide opportunity for farmers to adopt improved technology, intensify production, replenish soil nutrients and invest in more profitable enterprises when climatic conditions are favorable; and to more effectively protect their families and farms against the long-term consequences of adverse extremes. Research with smallholder farmers in low-income countries reveals a high level of interest and a range of promising management responses, but also highlights widespread communication failure (Hansen et al., 2010). Furthermore there is a mismatch between farmers' needs and the scale, content, format, or accuracy of available information products and services. These factors have limited the widespread use of seasonal forecasts among smallholder farmers. Adoption rates and reported benefits have been moderately high in pilot projects that have sought to overcome some of the communication barriers (Huda et al., 2004; Patt et al., 2005; Meinke et al., 2006; Roncoli et al., 2009).

Index-based insurance

Index insurance is an innovation that triggers payouts based on a meteorological index (e.g. rainfall or modeled water stress) that is correlated with agricultural losses, rather than observed losses. Basing payouts on an objectively measured index overcomes problems with moral hazard, adverse selection and the high cost of verifying losses (Skees and Enkh-Amgalan, 2002; Hess and Syroka, 2005; Barrett et al., 2007). Basis risk – the gap between an insured index and the risk it is meant to target – is regarded as the price paid for removing moral hazard, adverse selection and their resulting transaction costs as barriers to insuring vulnerable farmers against climate-related risk. Because it avoids the key problems that make traditional crop insurance unviable in most low-income countries, recent innovations have prompted a resurgence of interest in managing risk for smallholder agriculture through insurance. Recent reviews of index insurance initiatives targeting agriculture in low-income countries (Barrett et al., 2007; Hellmuth et al., 2009; Hazell et al., 2010) emphasize the need to develop a framework for targeting particular index insurance products to particular agricultural systems, build capacity to manage index insurance in the private sector, bundle insurance within broader suites of services, and develop indices that reduce basis risk particular where meteorological data are sparse.

Managing climate-related risk through the food system

The actions that governments and aid organizations take in response to climate shocks can have major impacts on farmers and local agricultural markets. Climate-driven price fluctuations can lead to acute food insecurity for the relatively poor who spend most of their incomes on food. Using climate-based forecasts of food production to better manage trade and stabilize prices, offers considerable potential benefits to both agricultural producers and consumers (Arndt and Bacou, 2000; Arndt et al., 2003; Hallstrom, 2004; Hill et al., 2004). Assistance, particularly food aid, in response to a major food crisis can have complex impacts on farmers and on agricultural markets (Barrett, 2002; Abdulai et al., 2004). Assistance can protect productive assets, foster investment and intensification through its insurance effect, and stimulate agricultural value chain development; but can contribute to price fluctuations, disincentives to agricultural production and market development, and a cycle of dependency of poorly targeted and managed. Although waiting for verifiable consumption or health impacts before initiating action may improve targeting, the resulting delay can greatly increase the cost of delivering assistance, and the long-term livelihood impacts of the crisis (Broad and Agrawala, 2000; Haile, 2005; Barrett et al., 2007). Improving the lead-time and accuracy of early warning information provides an opportunity to support more timely interventions.

Climate information services

Several of the promising opportunities to manage agricultural risk depend on climate information, and have not been fully exploited, in part because of gaps in existing climate information services. The gaps appear to be widespread globally. A multi-stakeholder assessment of the use of climate information in Africa describes inadequate use of climate information, across sectors and from local to policy levels (with a few noteworthy exceptions), relative to the scale of the development challenge (IRI, 2006). It attributed the substantial gap in the provision and use of climate information to "market atrophy" associated with long-term ineffective demand by development practitioners and inadequate supply of relevant climate information services. Positive responses to this gap include the Regional Climate Outlook Forums (RCOFS), which bring national meteorological services and a set of users from a region together to produce authoritative consensus seasonal climate forecasts, and discuss their potential application (Dilley, 2001).

Accelerated adaptation to progressive climate change

Progressive climate change, which refers to long-term changes in the baseline climate (i.e. changes in absolute temperatures and shifts in rainfall regimes) over periods of decades, presents the overarching major challenge to agricultural and food systems in terms of both policy and science. The key question for both food security and the agricultural economy is whether the food system can keep pace with growing demand in the face of climate and other drivers (Hazell and Wood, 2008). In many cases, this is unlikely; even without climate change, FAO predicts a need for increased cereal production in 2050 in the range of 70% to meet growing population sizes and dietary shifts (FAO, 2006).

The major challenge is therefore to enable accelerated adaptation without threatening sensitive livelihood systems as they strive to cope with stress. Accomplishing this task requires a multi-pronged strategy: analysis of farming and food systems, learning from community-based approaches, generation and use of new technologies, changes in agricultural and food supply practices including diversification of production systems, improved institutional settings, enabling policies, and infrastructural improvements, and above all a greater understanding of what is entailed in increasing adaptive capacity (Agrawal and Perrin, 2008; Tubiello et al., 2008). Some of these have a good track record. For example, germplasm improvement, improved management of crops, livestock, aquaculture and natural resources, and enhanced agrobiodiversity have all been shown to decrease susceptibility to individual stresses, and therefore constitute important tools for adapting to progressive climate change (Jackson et al., 2007). Nonetheless, significant knowledge gaps exist as to what adaptations options are available, what their likely benefits or costs are, where and when they should be deployed, and what the learning processes are that can support widespread change under uncertainty.

Adaptation can occur at multiple levels, from changed agricultural practices (e.g., staggering the crop calendar), to varietal change, to substitution or diversification, to moving out of crop farming, livestock rearing or aquaculture altogether. Many options that are technologically, economically and socially feasible are now emerging, some of which are outlined below (and covered in more detail in the background paper for this conference prepared by FAO). Options for technology, farming systems and policies will need to be packaged effectively to provide meaningful adaptation options for policy makers, food producers and consumers.

Technology development

Overcoming abiotic stresses in crops through crop breeding has proven to be an effective means of increasing food production (Evenson and Gollin, 2003), and arguably mitigating climate change effects (Burney et al. 2010). There is also substantial biological potential for increasing crop yields through conventional crop breeding (Ortiz et al., 2008) and the development of transgenic crops supported by biotechnology (Godfray et al., 2010). Investment in crop improvement to address specific characteristics of a progressively changing climate (e.g. heat, drought, waterlogging, pest resistance) is therefore an important component of any global effort to adapt farming systems. Targeting this investment effectively requires understanding the circumstances under which different abiotic stresses dominate (e.g. Thornton et al., 2009; Challinor and Wheeler, 2008) and matching crops to future climates in a way that accounts for uncertainties (e.g. Challinor et al., 2009c).

Better agricultural practices

Today's farming systems are adapted, to the extent possible given resource endowments, to the current climate conditions they experience, yet we know little about how well they will stand up to progressive climate change particularly as they come under increasing pressure from other global drivers. Many broad-scale analyses identify regions and crops that will be sensitive to progressive climate change (Jones and Thornton, 2003; Parry et al., 2007; Jarvis et al., 2008; Lobell et al., 2008), but there is sparse scientific knowledge as to how current farming systems can adapt, and which current farming systems and agricultural practices will enable adaptation. As climates effectively migrate, the transfer of best practices and technology from one site to the next will be crucial. Many of these are grounded in local knowledge. Candidate adaptation practices include agronomic innovations, planting strategies, improved livestock and fish management systems, pest and disease management, diversification of agriculture and livelihoods, and enhancement of agrobiodiversity (Easterling et al., 2007). The diversity of traits and characteristics among existing varieties of agricultural biodiversity (both inter- and intra-specific) provide enormous potential for adaptation to progressive climate change (Lane and Jarvis, 2007).

Enabling policies in food systems

Significant opportunities exist for national and sub-national policies that help enable adaptation at the community and household level. For example, policies that improve access and rights to water through investments in storage facilities or community-managed irrigation systems could aid rural communities in overcoming short- or long-term periods of drought (IWMI, 2009). The development of communal plans and strategies, such as pooling of financial resources or food storage facilities, may also prove invaluable. At the national level, concrete policy options include subsidies and incentives for crop substitution or expensive farming inputs (e.g. agrochemicals, bovine vaccines), as well as investment plans for improved infrastructure for food systems (e.g. transport). Public and private sectors and civil society organizations must work together to ensure that adaptation plans and strategies are coordinated through value chain and food systems. For example, since climate change will likely lead to extreme seasonal or annual production shocks, and countries have historically responded by restricting trade or pursuing large purchases in international markets (e.g. Chinese rice in 2008, Russian wheat in 2010), global strategies may be necessary to address agricultural price volatility (Battisti and Naylor, 2009) and to manage impacts such as large-scale land acquisition for food production for foreign markets (Cotula and Vermeulen, 2009). Under uncertain and highly dynamic changes in food systems, there is a considerable risk of conflicting policies and investments contributing to maladaptation.

Mitigating greenhouse gas emissions in agriculture

In 2005 agriculture contributed an estimated 10-12% of total anthropogenic emissions of greenhouse gases (GHGs). Reducing N_2O and CH_4 emissions, increasing C sequestration, or avoiding emissions through use of biomass for fuels or reduced land clearing are technical options to reduce emissions (Smith et al., 2007a). Global climate mitigation by agriculture for the period 2015–2020 could achieve approximately 1000 Mt CO_2-eq. below the "business-as-usual" scenario through 10% reductions in greenhouse gas emissions in concert with similar levels of improvement in the substitution of fossil fuels by biomass energy. If deforestation through agricultural expansion were reduced by 10% for the period 2015–2020 through agricultural development pathways that involve intensification, about a further 500 Mt CO_2-eq. could be stored (Smith et al., 2008).

Clearly, changes in farming practices can help reduce climate change, but whether society can also meet projected food needs under mitigation regimes remains unclear. Four issues underpin the joint achievement of food security and climate change mitigation: (a) the opportunities for sustainably intensifying agricultural production and avoiding conversion of high carbon landscapes, (b) the technical compatibility of food production and measures that reduce or sequester GHGs, (c) the need for inexpensive, on-farm measurement and monitoring to test real GHG budgets, and (d) the economic feasibility of and incentives for changing farming practices without compromising investments in food security. Innovation and capacity building will be required in all four areas. We review these challenges briefly to inform agricultural investments and policy.

Agricultural intensification

Producing more crops from less land is the single most significant means of jointly achieving mitigation and food production in agriculture, assuming that the resulting "spared land" sequesters more carbon or emits fewer GHGs than farm land (Robertson et al., 2000). The crop area in low-income countries is expected to expand 2-49% (Balmford et al., 2005), and avoided land conversions in the humid tropics and tropical wetlands are the most critical for mitigation (Paustian et al., 1998). Agricultural intensification (or the increase of yields per unit land area) is widely assumed necessary to meet projected food needs, given current economic and dietary trends (Gregory et al., 2005), and yield gaps still exist for rice and maize (Tilman et al., 2002). Burney et al. (2010) demonstrated that increases in crop productivity from 1961 to 2005 helped to avoid up to 161 Gt of carbon emissions and were a relatively cost effective intervention for mitigation, despite use of inputs that increased emissions. Similarly, Vlek et al. (2004) found that an increase of 20% of fertilizer on rice, wheat, and maize could take almost 23 million hectares out of cultivation without changing production.

But this "land sparing" effect of intensification is uneven in practice and requires policies and price incentives to strengthen its impacts (Angelsen and Kaimowitz, 2001). Investing in agricultural technologies to increase yields may have perverse effects, especially where demand for increased production is increasing, due for instance to population or income growth. Analyzing 961 agricultural sectors in 161 countries from 1970 to 2005 for 10 major crops, Rudel et al. (2009) found no paired relationship between crop yields and area cultivated. The authors observed that farmers tended to expand land areas with intensification, i.e. economic efficiency led to expansion not curtailment of the activity. Exceptions occurred in mostly temperate countries with conservation set-aside programs or where price supports were eliminated and imported grains substituted for local production. Similarly, Ewers et al. (2009), studying 23 crops from 1979 to 1999 in 124 countries, found that even where the per capita area of staple crops had declined slightly, the cultivation of non-staple crops often simultaneously increased, resulted in an expanded area of cultivated land. Declines were more likely where in low-income countries with existing large food supplies.

Intensification in the future will require more attention to the efficiency of inputs and their environmental costs (Matson et al., 1997; Gregory et al., 2002). Increased use of fertilizers, pesticides and fossil fuel energy as currently practiced may not be possible or desirable over the long term.. More efficient use of these inputs, more sustainable alternatives and breeding for efficiency will be required to reduce the carbon intensity (emissions per unit yield) of products, as well as reduce land areas and inputs that damage environmental health. (Tilman et al., 2002). For example, mid-term drainage and intermittent irrigation of wet rice systems appears to reduce methane emissions by more than 40%, with minimal impact on yields (Wassman et al., 2009). Precision fertilizer can result in higher yields per emissions. Agricultural intensification will require appropriate institutional and policy support to create environmental benefits as well as increases in crop yields for smallholders (Pretty et al., 2003).

Technical compatibility

The other major option is to farm in ways that reduce GHG emissions or sequester more carbon without reducing food production. The potential trade-offs and synergies between mitigation practices and food production have been well reviewed (Lipper et al., 2009). Enhancement of soil carbon through for example conservation tillage or management of crop residues (Lal 2004), and to a lesser extent agroforestry (Verchot et al., 2007) or high productive grassland restoration (Smith et al., 2008; Olsson and Ardo, 2002; Batjes, 2004) are expected to have significant impacts on climate without compromising food production. These technologies do have a saturation or maximum point though that will occur in 50-100 years beyond which further sequestration is not possible (Paustian et al. 1998). Enhancing soil carbon also has important environmental benefits in terms of water storage, soil biodiversity, and soil aggregate stability. Sustainable agricultural land management (SALM) is an umbrella term for practices expected to enhance productivity and mitigation. SALM should also enhance agroecosystem resilience and adaptation to climate change (Smith and Oleson, 2010). Soil carbon sequestration is estimated to have the highest economic mitigation potential (Smith et al., 2007a), although incentives for its adoption, as well as permanence, variability and monitoring need to be addressed. FAO has shown that areas with large food insecure populations also tend to have soils lacking carbon (FAO, 2009b), suggesting that these locations would be suitable for SALM approaches to mitigation.

Measurement and monitoring

Since mitigation measures can potentially affect the cost, yields and sustainability of food, getting more precise estimates of mitigation and its related effects on food systems (Ericksen, 2009) is essential to assessing actual trade-offs. Mitigation potentials remain uncertain as most have been estimated through highly aggregated data (Paustian et al., 2004). Greenhouse gas budgets at the local and national levels for specific farm practices, foods and landscapes are often unavailable, especially in low-income countries. Full accounting of GHGs across all land uses will be necessary to account for leakage and monitor the impacts of intensification. Measurement technologies are well known, but monitoring of indicators and life cycle analysis can be expensive and interactions among farm practices difficult to assess. Current efforts of the Global Research Alliance are focused on research to measure and enhance mitigation in industrialized agriculture. Similar efforts are needed for smallholder farming in low-income countries, which are major contributors to emissions. FAO's Mitigation of Climate Change in Agriculture (MICCA) project, the Cool Farm Tool assessments of the Sustainable Food Lab, GEF's Carbon Benefits Project, the UK-China Sustainable Agriculture Innovation Network (SAIN), IFPRI's Climate Change Mitigation and High Value Food Crops project, and CCAFS are programs that will contribute toward this aim. Comparable measurements are needed both for carbon intensity (CO_2-eq. per unit food or per tons yield) and land–based emissions (CO_2-eq. ha^{-1}) to compare efficiencies and aggregate among like units.

Economic feasibility and incentives
Knowledge of the economic feasibility of agricultural mitigation and its links to investments in food security need improvement (Cannell, 2003). Smith et al. (2007b) estimate that less than 35% of the total biophysical potential for agricultural mitigation is likely to be achieved by 2030 due to economic constraints. Measurement costs and the transactions costs associated with start-up costs and aggregating among numerous smallholders are presently major barriers that require innovation. The uncertainty of carbon prices and the policies supporting them also presently limit the technical potential for implementing mitigation.

Farmers and others driving the expansion of cultivated areas will require incentives to undertake mitigation practices. Lessons should be gleaned from existing national schemes for payments for environmental services programs to farmers, such as those that exist in the European Union, Australia, Canada, Japan, Norway, Switzerland and US (Tilman et al., 2002). International agreements that enable agricultural GHG reductions to count towards countries' emissions reductions commitments could create an important policy incentive (Paustian et al., 2004). Understanding the potential for mitigation through alternative agricultural development pathways and the incentives driving them will be important for transforming agriculture towards more sustainable practices. Compliance with mitigation standards before receiving farm assistance, taxes on fertilizers or pesticides (or removal of subsidies), voluntary markets and consumer-related incentives related to labeling are all additional options for creating incentives (Tilman et al., 2002). The revenues generated by even moderate levels of agricultural mitigation (USD20 per t CO_2) equivalent should yield USD30 billion in annual revenues that could also be used to encourage additional investments in mitigation or food (FAO 2009c).

Implications for policy support to GHG mitigation in the smallholder agricultural sector
Investments in technological innovation and agricultural intensification strategies should be linked to increased efficiency of inputs, and to comprehensive land use policies and payments for environmental services that discourage forest conversion and negative environmental impacts. Impacts on smallholders should be monitored. Investments should also be made in technical and institutional innovations that reduce the costs of mitigation and increase incentives for the implementation of mitigation. These investments would enhance the technical biophysical potential for reducing GHGs from agriculture. Incentives for sustainable agricultural land management (SALM) are also needed, either through government programs or voluntary market payments, targeting areas with high potential mitigation first for highest impact. Technical compatibilities need to be field-tested on farms. Finally, developing a better understanding of the GHG budgets for specific mitigation practices on smallholder farms and landscapes and for food products, and developing simple, inexpensive monitoring techniques for use in low-income countries is a priority.

Linking science with policy and other actions

Knowledge must be linked with action – changes in policies, institutions, technologies and management strategies – if it is to help enhance food security and resilience to climate change. For example, national adaptation programs of action (NAPAs) are being developed in many countries by national ministries of environment with the support of the United Nation's Development Program (UNDP), but most are not based upon scientific evidence as to the range of relevant adaptation options and impacts in different environments, or of the critical role institutions play in future adaptation of rural livelihoods (Agrawal and Perrin, 2008). Reasons for the disconnect between science and policy may be that the knowledge most needed by policymakers and other action-oriented stakeholders is not given priority in research and development efforts, nor is communicating it in ways that best support decision making, management and policy (Cash and Buizer, 2005). Further issues with perceptions of untrustworthiness and political bias in scientific work (Clark and Holliday, 2006) are illustrated by the recent incident in which climate scientists' email conversations were hacked and sections selectively made available on the internet, leading to perceptions by some that the climate change evidence was rigged (Hickman and Randerson, 2009).

Credibility (perceived technical quality and authority of information), salience (perceived relevance to users' decisions) and legitimacy (perception that the information service seeks the user's best interest) have been proposed as prerequisites for successful use of climate information for agriculture (Cash and Buizer, 2005; Meinke et al., 2006; Crane et al., 2010). Credibility – in the sense of providing authoritative forecasts through national meteorological services in the face of multiple (and sometimes conflicting) information sources – was part of the rationale for the RCOFs (Dilley, 2001; Orlove and Tosteson, 1999). The climate community has invested in credibility through processes such as the Regional Climate Outlook Forums (Dilley, 2001). However, institutional arrangements that gave farmers and other agricultural stakeholders little influence over the design of products (at a cost to salience) and little ownership of the process (at a cost to legitimacy) may contribute to the gap between needed versus available climate information (Cash et al., 2006; Hansen et al., 2007). Giving farmers and other agricultural stakeholders a more effective voice in the design of climate information products and services can bridge this gap. Greater investment is also needed in the capacity of rural communities to access, interpret and act on climate-related information.

In short, climate change demands rethinking of how research is done – with primary emphasis on active integration with policy and implementation. New initiatives such as the program on Climate Change, Agriculture and Food Security (CCAFS) and ClimDev-Africa may re-invigorate how climate knowledge informs agricultural practice. What distinguishes many of these initiatives is their commitment to collaboration among partners from different sectors and backgrounds. Research into mechanisms to create influential knowledge suggests that it generally requires active collaborations between researchers and particular decision-makers, with trusted intermediaries or "boundary spanners" often playing a crucial integrative role (Agrawala et al., 2001, Cash et al., 2003).

The role of the private sector, and building public-private partnerships (and the challenges in doing so) is also increasingly recognized as important in supporting the kind of generation of knowledge in the agricultural sector that is needed to deal with food security and climate change challenges (Spielman et al., 2007). For example, 25 of the world's largest agrifood companies have created an integrated platform for sharing best practices (the Sustainable Agriculture Initiative; www.saiplatform.org), which is developing the Cool Farm Tool, described in an earlier section of this paper, among other activities. While private sector actions are not a substitute for public obligations, there are bountiful opportunities for private sector innovation to support adaptation and mitigation in the agricultural and food sectors (Forstater et al., 2009; UNEP, 2009).

Tools for linking knowledge with action are increasingly tested and applied by interdisciplinary, multi-organizational research-for-development teams (Kristjanson et al., 2009). Examples include participative mapping of impact pathways (Douthwaite et al., 2007; Reid et al., 2010), negotiation tools informed by research (van Noordwijk et al., 2001), social network analysis, innovation histories, cross-country analyses and game-theory modeling (Spielman et al., 2009). But there is much yet to discover about means to improve the links between knowledge and action, and, critically for climate change approaches, about the interactive links between science and policy. For example, political science analyses of policy making are not yet well utilized by climate change and food security communities. Efforts aimed at increasing the knowledge and capacities of farmers' organizations to innovate, along with strengthening of networks and alliances to support, document and share lessons on farmer-led innovation are also needed (Clark et al., 2010). Other needs include innovative engagement and communication strategies to ensure that scientific results inform international policy processes (e.g. UNFCCC), regional (e.g. adaptation funds) and national processes (e.g. NAPAs and NAMAs) – these different audiences will likely require different strategies to elicit effective responses.

Conclusions: appropriate research and action in the face of uncertainty and interdependence

Significant uncertainty exists regarding the direction and magnitude of climate change, which in turn leads to uncertainty in the realm of food production and its impact on food systems and food security across complex geographies and societies. It remains to be seen whether uncertainty propagates, remains the same or reduces along the causal pathways and associated analysis from climate science through agriculture to human systems. Research in agriculture, food security and climate change must continue to improve understanding of uncertainty, to allow more confident decision-making and allocation of limited resources towards new climatic futures.

Food systems faced with climate change need urgent action in spite of uncertainties. The urgency of climate change provides a new impetus for paradigms of integrated research, policy and action. There is a pressing need to invest in databases and tools to inform policy and practice in the spheres of agricultural risk-management, adaptation and mitigation; these need to be co-developed with users. Likewise, initiatives to develop capacity to tackle climate change impacts on farming and food must address not only scientific capacity but also the capacity of users to demand, interpret and apply scientific outputs effectively. Decision-makers need not just a holistic view of the system but rather a strategic approach that focuses on key dependencies and processes. Some of the work outlined above demonstrates that this approach can work for well-defined subcomponents of the farming system, for example crop yield. A key challenge in assuring future food security is to apply such approaches across the whole food system and across multi-purpose landscapes. This calls for collaboration among researchers and practitioners from a range of backgrounds, sectors and disciplines.

Action will need to move ahead of knowledge, with decisions made and reviewed on the basis of emerging research and consensus. This paper has provided a brief review of the state of knowledge in the key areas of managing climate variability and risks, accelerating adaptation to progressive climate change, mitigating greenhouse gas emissions from the agricultural sector, and generating relevant knowledge for policy. Major research questions for each of these areas are outlined below.

Managing climate variability and risks

- How effectively do rural communities manage climate-related risk, and which local strategies hold promise for transferring and upscaling?
- What combination of livelihood diversification, intensification, innovation and risk transfer has the best prospect for building resilience and reducing the long-term climate vulnerability of rural communities?
- What combination of new products, services, delivery mechanisms and institutional arrangements offers the best opportunity to deliver useful, equitable, transferable and scalable climate risk-management in rural areas?
- What is the feasibility and best strategy to use advanced information to target and initiate safety net interventions and responses to climate-related market fluctuations and emerging food crises?

Accelerated adaptation to progressive climate change

- How can information from global climate models and regional climate models be incorporated into support for adaptation processes that in agriculture and food systems are both location-specific yet robust enough to apply across the range of plausible climate futures?
- How can climate-driven shifts in the geographical domains of varieties, cultivars, wild relatives, pests and diseases, and beneficial soil biota be anticipated and best managed to protect food security, rural livelihoods and ecosystem services?
- Given rapid change in non-climatic drivers, what is the best approach for integrating individual technological, biodiversity management, livelihood, market adaptation and policy options into comprehensive local-level adaptation packages?
- How do social, cultural, economic and institutional factors mediate adaptation processes at the local level and how can these be mobilized to improve resilience?

Mitigating greenhouse gas emissions from the agricultural sector

- What are alternative trajectories for low carbon agricultural development and how can they be managed to secure food production while providing for livelihoods and food security?
- What technologies and management systems can deliver reduction of emissions and sequestration of greenhouse gases (GHGs) cost-effectively with maximum benefits to poverty alleviation, food security and environmental health at the landscape level?
- What is the GHG abatement potential, technical feasibility and economic feasibility of different agricultural mitigation practices among smallholders in low-income countries?
- What institutional arrangements and incentives can enable the poor, especially women, participate in the design of and gain better access to the benefits available through the trade of carbon and other GHGs?

Generating relevant knowledge for policy

- What are plausible futures for agriculture and food systems, encompassing interactions among changes in climate and other key drivers of agricultural systems and food security?
- What are the main factors causing vulnerability to climate change and climate variability among agricultural and food systems and the people who depend on them, and how may this vulnerability change in the future?
- What are the consequences of international, national and local policy and program options for improving environmental benefits, enhancing livelihoods and boosting food security in the face of a changing climate?

Actions taken over the next decade will be critical. Responses need to come quickly, faster than the pace of change in climate. Actions towards adaptation firstly entail better management of agricultural risks associated with increasing climate variability and extreme events, for example improved climate information services and better safety nets. Additionally, we need accelerated adaptation to deal with progressive climate change in the coming decades. Feeding nine billion people in 2050 requires transformation of agriculture – growing more food without exacerbating environmental and social problems under climate change. Maximization of agriculture’s mitigation potential will require, among other interventions, investments in technological innovation and agricultural intensification linked to increased efficiency of inputs, and creation of incentives and monitoring systems that are inclusive of smallholder farmers. We need to integrate and apply the best and most promising approaches, tools and technologies. The involvement of farmers, policy-makers, the private sector and civil society in the research process is vital. Successful mitigation and adaptation will entail changes in individual behavior, technology, institutions, agricultural systems and socio-economic systems. These changes cannot be achieved without improving interactions between scientists and decision-makers at all levels of society.

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The CGIAR Challenge Programme on Climate Change, Agriculture and Food Security (CCAFS):
An Opportunity for Collaboration between the CGIAR and the Belmont Forum/IGFA

Suggestions for Such Opportunities for Discussion at the Forum/IGFA Meetings in
Cape Town, 25-29 October 2010

The Consultative Group on International Agricultural Research (CGIAR) has established and initiated planning and funding for a new program on climate change, agriculture and food security. This programme was adopted in response to a proposal whose preparation involved fifteen CGIAR centers and numerous research and development partners.

It may be of interest to note that major supporters of the CGIAR include eight major donor countries (Australia, Canada, the European Commission, Japan, Norway, Sweden , the United Kingdom and the United States); multilateral and global organizations, such as the World Bank; and foundations, such as the Bill and Melinda Gates Foundation.

The CCAFS and the Forum have begun exploring needs and opportunities for collaboration through exchanges of correspondence between Dr. Thomas Rosswall, the Chair of the CCAFS Steering Committee, and Dr. Albert van Jaarsveld, President of the National Research Foundation of South Africa. Dr. Jaarsveld was asked by the Forum in January 2010 to assume responsibility for interaction with the CCAFS (access to a key element of this exchange is available through the website for the Cape Town Meeting).

Dr. Rosswall, CCAFS, has suggested that "engagement of the Belmont Forum/IGFA can assist in moving the science agenda forward and result in strengthened collaboration between the global change and development research communities". He has identified five specific areas in which such engagement could be especially useful. These are, very briefly, as follows:

1. An initiative for priority actions in Sub-Saharan Africa, in conjunction with a Joint Programming Initiative (JPI) of European countries led by the EC and strongly supported by France. He has suggested that the Earth System Science Partnership (ESSP) might be an appropriate vehicle through which the Forum/IGFA could advance such an initiative.

2. An initiative under the Global Research Initiative on Agricultural Greenhouse Gases. Such an initiative might focus on the role of soil carbon in agricultural emissions. This is also a JPI activity, but with New Zealand playing an especially important role.

3. An initiative to "address linked ecological (and) social systems, especially through (identification of) research sites … that could become part of the PECS network (ICSU's Programme on Ecosystems and Society) … (and thus) fill some of the science Gaps identified during the Millenium Ecosystem Assessment". Such a programme could emphasize bringing together "scientists from the South and the North to engage in research on agriculture and global change in the context of linked ecological-social systems". This could "support science in the forefront of policy-relevant research while strengthening the integrated, regional approach of the CCAFS science agenda". Such a programme might be particularly relevant to the UK effort in the area of Ecosystem Services for Poverty Alleviation.

4. CCAFS scenario-related activities in "the three CCAFS priority regions: East and West Africa and the Indo-Gangetic Plain. This would build on experience gained from the IPCC and the Millenium Ecosystem Assessment.

5. An effort could be undertaken under the Global Framework for Climate Services (GFCS) "for the CCAFS … to link up with the climate research community … primarily through the WCRP … and (thus) to foster links between national hydromet services and national agricultural research systems". It is suggested that the Forum/IGFA could assist in this area by encouraging interaction between research scientists working under the CCAFS Workplan; the WCRP and the WMO Agricultural Meteorology Programme.

It is suggested that the Forum discuss ways to pursue these possibilities, but perhaps focusing on the PECS network and the GFCS. With regard to the PECS, the linkages between climate change, ecosystems in general, and agricultural systems in particular, are strongly relevant to a wide range of Forum/IGFA members activities and to the objectives of the Belmont Agenda and the ICSU visioning exercise. With regard to the GFCS, it appears that there is great potential to forge new links between the global change research community and the WMO to enhance the WMO's efforts to develop the GFCS and to encourage the development of national climate services. The Forum/Council will be receiving a presentation from the WMO about their ongoing efforts regarding the GFCS.

It is proposed that these initiatives, in pursuance of the Belmont Challenge, also concentrate on regional cooperation. Africa in particular is a region of mutual interest to both the CCAFS and the Forum/IGFA; for this reason, among others, it is suggested that the Forum/IGFA offer to co-sponsor either one or both of the initiatives with the CCAFS and that the Forum/Council's activities be coordinated through the ad hoc task team under the leadership of Dr. Jaarsveld and the NRF.

In getting these initiatives underway, it is suggested that joint scientific planning activities such as the convening of scientific workshops or similar meetings, be undertaken. It is also suggested that the START program be invited to associate with these initiatives as this group is supporting ongoing scientific capacity-building activities which are directly related to CCAFS.

MP7 Proposal: Climate Change, Agriculture and Food Security: Extract on Capacity building

MP7 will make a lasting difference through a strategic, fully embedded focus on capacity building. To achieve its overall goals, the two related areas in which MP7 needs to raise capacity are: (1) researchers' capacity to generate knowledge on managing agriculture and food security under climate change; and (2) multiple stakeholders' capacity to demand, shape and use this knowledge effectively to develop, implement and review policy and technical options in a dynamic environment. These stakeholders include members of farmers' organizations and other community-based organizations; frontline extension agents and development workers; policy makers in civil service departments, parliaments and funding agencies; opinion-formers in civil society, research organizations, national meteorological services (NMS), university networks and the media; and managers and strategists in businesses and NGOs. The vision for capacity development is to enable a co-learning approach between researchers and other stakeholders, building on and enhancing the knowledge and skills of both through structured cross-disciplinary interactions.

Three principles will guide capacity building within MP7. The first is to add value through partnership, by complementing existing capacity-building programs rather than establishing new programs, undertaking joint activities that build on comparative advantages and provide mutual benefits, and working with networks rather than single stakeholder groups. The second is to take a systems approach, acknowledging that capacity building requires institutional investment, not just training packages for individuals, and that agriculture and food security need innovation in governance and institutional change as well as technical agricultural advances to cope with the challenges of climate change. The third is to promote integration rather than add-on of capacity-building activities, ensuring that development of new tools, knowledge and evidence within the research themes includes strategies and resources for building the capacity of researchers and stakeholders to use, adapt and critique these outputs.

Each of the four research themes includes attention to capacity-building outcomes, achieved by working closely with partners. The global change System for Analysis, Research and Training (START, a nongovernmental research organization within the ESSP that has a strong track-record in assisting developing countries to build the expertise needed to understand and respond to global and regional environmental change) will be a key partner. Others include the community-based adaptation network AfricaAdapt, women's organizations such as Women's Environment and Development Organization (WEDO) and university networks such as Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) and African Network for Agriculture, Agroforestry and Natural Resources Education (ANAFE).

In building researchers' capacity, MP7 will focus on mid-career scientists and post-graduate students, working with partners to provide opportunities for researcher capacity development in ways that also contribute to the research goals of MP7.

MP7 also aims to build capacity among farmers, policy makers, the private sector and civil society to develop knowledge-based policy options and to apply, monitor and adapt these options. MP7 will work strategically with partners to reach this wide spectrum of stakeholders, working with associations and organizations rather than attempting to reach many thousands of individual farmers.
…

CGIAR Challenge Programme on
Climate Change, Agriculture and Food Security (CCAFS)

4 June 2010

Dr. Albert van Jaarsveld
President and Chief Executive Officer
National Research Foundation
P. O. Box 2600
Pretoria 0001
South Africa

Re. Belmont Forum and Food Security Research

Dear Albert,

As a follow-up to my letter dated 26 April, members of the CCAFS Steering Committee discussed various options for cooperation on the further development of research priorities and opportunities in the area of global change and food security. In conjunction with our SC meeting the first week of May, CCAFS arranged a conference to engage with stakeholders in the area of climate change, agriculture and food security. We were pleased that David Allen attended this meeting and I took the opportunity to discuss your letter and our possible response with him. This meeting also provided excellent opportunities to discuss how CCAFS could be transformed into one of the new CGIAR MegaProgrammes (MP), which has been selected for fast-tracking. CCAFS was asked to provide a proposal for such a transfer to a MP. It was very clear that the ESSP partnership was much appreciated and in the submission of CCAFS of a proposal for a MP, we stressed the importance of CGIAR-ESSP collaboration also for a new MegaProgramme to be built on the foundation of CCAFS. Thus, there is a window of opportunity for the global change research community to further engage with the development research community through the CGIAR centres in the context of CCAFS and the MP and to expand on current CCAFS collaboration. It is in this context that we would like to see further engagement with the Belmont Forum.

In our discussion we have tried to identify opportunities for strengthened ESSP-CGIAR collaboration and engagement of the Belmont Forum members in the area of food security research. We have thus identified five potential areas of collaboration, where we think engagement of the Belmont Forum/IGFA can assist in moving the science agenda forward and result in strengthened collaboration between the global change and development research communities.

1. **The Joint Programming Initiative (JPI) of 20 EU, and affiliated, countries on "Agriculture, Food Security and Climate Change".** The initiative (Annex 1) currently consists of 20 countries represented by Ministries and/or research funding bodies. The membership of the Scientific Advisory Board (Annex 2) and the Governing Board (Annex 3) are enclosed for your information. The Scientific Advisory Board, of which I am a member, is charged with elaborating a common strategic vision and a list of priority actions by the end of 2010. It is our hope that the JPI will engage the European science community in global change and food security issues and that member countries will develop joint calls for proposals. The JPI has suggested that collaboration should be developed with Sub-Saharan Africa, where CCAFS could have an important role to play. The JPI and CCAFS will also have complementary roles and provide jointly a platform to address climate change and food security in a global context. It is hoped that the JPI will engage with other OECD countries in bilateral discussions, so that additional partnerships can be built. It should be noted that five of the 12 SAB members are "Non-European or affiliated with international agencies". We also hope that this JPI will provide the context for collaboration between EC DG Research and DG Development. Since some IGFA members are engaged in the JPI, the Belmont Group may consider this as one priority activity, which could support a direct link between ESSP and this initiative. The French Institut National de la Recherche Agronomique (INRA) provides the interim secretariat for the JPI.

   In addition, the ESSP Joint Initiative Global Environmental Change and Food Systems, GECAFS, which is currently in its synthesis phase, was very much involved in organizing a meeting at the Royal Society in London last February on "Environmental Change and Agriculture" with several participants representing CCAFS. The meeting addressed the need for additional collaboration as GECAFS was entering into its wrap-up phase. The report from this meeting is enclosed as Annex 4. The meeting was organized in conjunction with a Royal Society Discussion Meeting on "Greenhouse gases in the Earth system: setting the agenda to 2030".

2. **The Global Research Alliance on Agricultural Greenhouse Gases** — launched at the Copenhagen climate summit in December 2009 — held its first meeting in Wellington, New Zealand, in April with 28 of the 29 member states in attendance. The Alliance aims to bridge gaps in research on agricultural greenhouse gas emissions, which account for around 14 per cent of the world's total emissions. It also seeks to coordinate such research on an international scale, ensuring that scientists share their findings with research communities and farmers in other countries as well as their own. Alliance members agreed on three research strands: crop management research led by the United States; livestock issues led jointly by the Netherlands and New Zealand; and rice paddy farming investigations led by Japan. A further research area to study the role of soil carbon in agricultural

emissions is also under consideration. This will be highly relevant for CCAFS Theme 6 and a representative of the Alliance was also present at the Royal Society meeting last February. Member states, including 13 developing countries, can decide which research groups are most relevant to their needs and join any of them. The work across all three strands will initially focus on mitigation of greenhouse emissions and research must be clearly defined to avoid overlap with existing knowledge. CCAFS secretariat is in close contact with the Danish representative to the Alliance, and Jean Francois Soussana, a member of the SAB of the JPI, attended the Wellington meeting as a member of the French delegation. There are thus excellent opportunities for strong CCAFS-JPI-Research Alliance collaboration and the Belmont Forum can again play an important role.
A draft charter for the Alliance will be finalised in 2011 and New Zealand will act as the interim secretariat.

3. **ICSU Programme on Ecosystems and Society (PECS**) will develop research sites to address linked ecological-social systems. CCAFS has discussed the possibility to engage in the discussion on site selection so that a few of its sites could also become part of the PECS network. This will also provide an excellent link between CCAFS and the plans to establish an Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). PECS was established to fill some of the science gaps identified during the Millennium Ecosystem Assessment (Annex 5). Financial support to allow scientists from the South and the North to engage in research on agriculture and global change in the context of linked ecological-social systems would support science in the forefront of policy relevant research while strengthening the integrated, regional approach of the CCAFS science agenda. It would be interesting to consider the possibility of establishing a programme at the international level similar to the one set-up by DfID, ESRC and NERC on Ecosystem Services for Poverty Alleviation (http://www.nerc.ac.uk/research/programmes/espa/).

4. **CCAFS scenario work** will build on the experiences of GECAFS and initial work will be coordinated from the University of Oxford by John Ingram. Scenario work will be important in both CCAFS and for the MegaProgramme and will initially focus on the three CCAFS priority regions; East and West Africa plus the Indo-Gangetic Plain. Scenario work is important for guiding the science but also to engage stakeholders in participatory approaches to evaluate possible futures. Belmont Members could provide direct support to this component of CCAFS through the University of Oxford. The exercise will also build on experiences from IPCC and the Millennium Ecosystem Assessment scenario work and provide a link between CCAFS and the assessment community.

5. **Climate services.** The World Climate Conference – 3 in August-September 2009 decided to establish a Global Framework for Climate Services to strengthen production, availability, delivery and application of science-based climate prediction

and services (Annex 6). CCAFS has provided input to the initial planning on behalf of CGIAR (Annex 7). It is crucial for CCAFS and the MegaProgramme on Climate Change to link up with the climate research community at the international level (primarily though WCRP) and to foster links between national hydromet services and national agricultural research systems at the national level. WCRP will provide the research necessary for climate services (in collaboration with the national hydromet services) and will feed into the CCAFS scenario development. The Belmont Forum can assist in establishing such links through the support of relevant section of the CCAFS Workplan in collaboration with WCRP and the WMO Agricultural Meteorology Programme.

With the above five examples, we wish to put forward some initial ideas on how the Belmont Forum/IGFA can engage with CCAFS in moving the agenda on global change and food security forward. We are convinced that Members of the Belmont Forum will add additional suggestions and that we jointly can develop an agenda for specific discussions during the meeting of the Belmont Forum/IGFA in Cape Town in October or in another context that would be mutually agreeable.

We see your letter and our response as the first steps in an iterative process that can hopefully lead to discussions and concrete output from the October meeting. We are looking forward to your initial reactions and to move this dialogue forward.

With my best personal wishes,

Yours sincerely,

Thomas Rosswall
Chair, CCAFS Steering Committee

Thomas Rosswall
Chair, CCAFS Steering Committee
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06530 Le Tignet
France

thomas.rosswall@gmail.com

Annexes

1. Agriculture, Food Security and Climate Change. A Joint Programming Initiative of currently 20 European Members.
2. Members of the Scientific Advisory Board, JPI
3. Members of the Governing Board, JPI
4. Report from meeting on Environmentaal Change and Agriculture, Royal Society, London 25 February 2010
5. Carpenter, S. R. *et al.* Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. PNAS 106:1305-1312 (2010).
6. High-level declaration, World Climate Conference – 3
7. CCAFS reponse to WMO, on behalf of CGIAR, re. Climate services

World Climate Conference – 3

Geneva, 31 August – 4 September 2009

CONFERENCE DECLARATION

We, Heads of State and Government, Ministers and Heads of Delegation present at the High-level segment of the World Climate Conference-3 (WCC-3) in Geneva, noting the findings of the Expert Segment of the Conference:

Decide to establish a Global Framework for Climate Services (hereafter referred to as "the Framework") to strengthen the production, availability, delivery and application of science-based climate prediction and services;

Request the Secretary-General of the World Meteorological Organization (WMO) to convene, within four months of the adoption of the Declaration, an intergovernmental meeting of Member States of the WMO to approve the terms of reference and to endorse the composition of a task force of high-level, independent advisors to be appointed by the Secretary-General of the WMO with due consideration to expertise, geographical and gender balance;

Decide that the task force will, after wide consultation with governments, partner organizations and relevant stakeholders, prepare a report, including recommendations on proposed elements of the Framework, to the Secretary-General of WMO within 12 months of the task force being set up. The report should contain findings and proposed next steps for developing and implementing the Framework. In the development of their report, the task force will take into account the concepts outlined in the annexed Brief Note;

Decide further that the report of the task force shall be circulated by the Secretary-General of WMO to Member States of the WMO for consideration at the next WMO Congress in 2011, with a view to the adoption of the Framework and a plan for its implementation; and

Invite the Secretary-General of WMO to provide the report to relevant organizations and to the UN Secretary-General.

Adopted by acclamation by the High-Level Segment of the Conferenceon 3 September 2009

WORLD CLIMATE CONFERENCE – 3

31 August – 4 September 2009, Geneva, Switzerland

Global Framework for Climate Services

BRIEF NOTE[*]

The World Climate Conference – 3 proposes to create a Global Framework for Climate Services through which the developers and providers of climate information, predictions and services, and the climate-sensitive sectors around the world, will work together, to help the global community better adapt to the challenges of climate variability and change. This BRIEF NOTE presents an overview of the Framework, by answering a series of key questions.

Why is a Global Framework for Climate Services Necessary?

1. Many socio-economic sectors, including water, agriculture, fisheries, health, forestry, transport, tourism and energy, are highly sensitive to weather and climate extremes such as droughts, floods, cyclones and storms, heat waves or cold waves. Decision-makers in these sectors are increasingly concerned by the adverse impacts of climate variability and change, but are not sufficiently equipped to make effective use of climate information to manage current and future climate risks as well as ecosystems. Consequently, there is not only an urgent need for enhanced global cooperation in the development of accurate and timely climate information but an

equally urgent need for its exchange between the providers and users of climate services, thus ensuring that relevant climate information is integrated into planning, policy and practice at various levels.

2. Recent advances in science and technology offer the prospect of further improvements in quality of climate information and prediction services. Integrating seasonal to multi-decadal predictions and long-term climate projections into decision-making in all socio-economic sectors, through an effective two-way dialogue between providers and users on the range, timing, quality and content of climate products and services, will ensure that decisions relating to managing climate risks are well informed, more effective and better targeted.

3. In order to address the need for improved climate information and to provide an effective interface between scientists, service providers and decision-makers, the World Meteorological Organization (WMO) and its partner organizations for the World Climate Conference-3 propose the development of a new Global Framework for Climate Services (also referred to as the 'Framework') with the goal to:

> ***"Enable better management of the risks of climate variability and change and adaptation to climate change at all levels, through development and incorporation of science-based climate information and prediction into planning, policy and practice."***

What is the Global Framework for Climate Services?

4. The Global Framework for Climate Services is proposed as a long-term cooperative arrangement through which the international community and relevant stakeholders will work together to achieve its stated goal.

5. The Framework will have four major components: Observation and Monitoring; Research, and Modelling and Prediction; a Climate Services Information System; and a User Interface Programme (Fig. 1). The first two components are well established but are in need of strengthening. The latter two components together constitute a 'World Climate Service System'.

6. The User Interface Programme, which presents a relatively new concept, will develop ways to bridge the gap between the climate information being developed by climate scientists and service providers and the practical information needs of users. Recognizing that the needs of the user communities are diverse and complex, it will

support and foster necessary institutional partnerships, cross-disciplinary research,

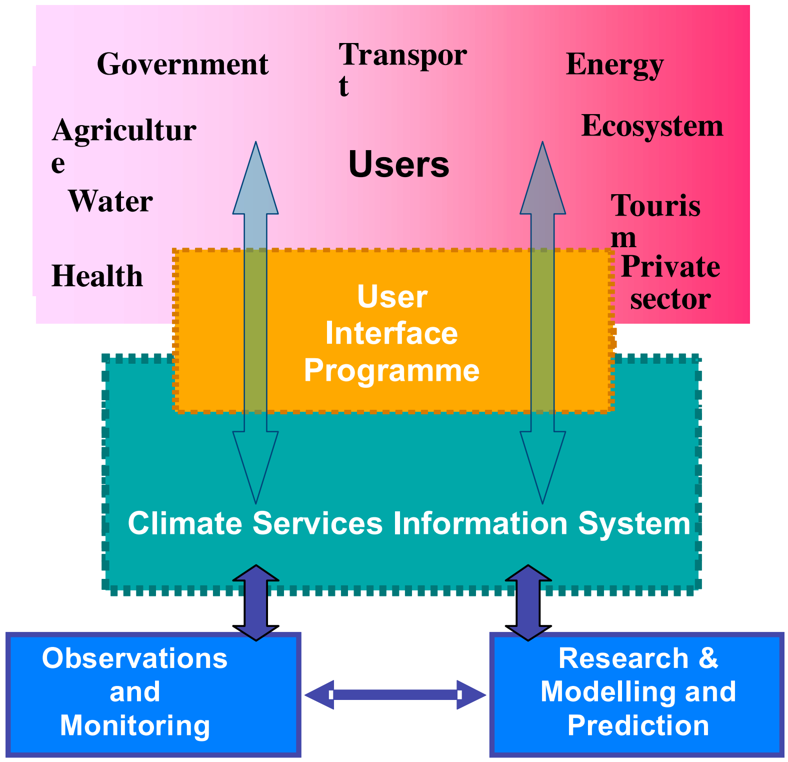

Figure 1: Components of Global Framework for Climate Services

innovation, development of decision support tools and climate risk management practices, generation and capture of knowledge, evaluation and establishment of best practices, education, capacity building and service application for decision making. The outcomes of the User Interface Programme will be reflected in the operational services of the Climate Services Information System.

7. The Climate Services Information System (CSIS) will build on established global programmes such as the World Climate Programme and will reinforce, strengthen and better coordinate the existing institutions, infrastructure and mechanisms but importantly, will focus on user-driven activities and outputs, while continuing to implement science-and technology-driven ones.

8. The CSIS, through a network of global, regional and national institutions, will synthesize information streaming from the Observation/Monitoring and Research/Modelling components of the Framework, and will create information, products, predictions and services in an operational mode at various spatial scales.

These services will be enhanced by feedback from users and other components of the system, and by the outputs of the User Interface Programme, thereby ensuring the development and delivery of ***user-oriented*** climate information and prediction services. It will focus, in addition, on standardization, exchange and quality assurance of information and communicating the highest quality information, products and services possible to decision-makers from global to local scales. Through enhanced international cooperation for development and transfer of technology related to meteorological services and mobilization of resources, this System will also build capacity among national and regional meteorological service providers in developing and least-developed countries, whose contributions are essential for improved climate information products at global, regional and national scales.

What will be achieved through Global Framework for Climate Services?

9. The Framework, when fully implemented, will support disaster risk management and climate risk management practices, and will contribute to achieving the objectives of various Multilateral Environmental Agreements (MEAs) such as the United Nations Framework Convention on Climate Change (UNFCCC), and of internationally agreed upon goals including the Millennium Development Goals. Effective implementation of the four components of the Framework would lead to the following:

- Strengthened local, national, regional and global observational networks and information management systems for climate and climate-related variables ;
- Enhanced climate modeling and prediction capabilities through strengthened international climate research focused on seasonal to decadal timescales;
- Improved national climate service provision arrangements based on enhanced observation networks and prediction models, and greatly increased user interaction;
- More effective use of global, regional and national climate information and prediction services by all stakeholders in climate-sensitive sectors in all countries (leading to improved planning and investment in sectors vital to national economies and livelihoods); and thereby

- Widespread social, economic and environmental benefits through more effective climate risk management and increased capacities for adaptation to climate variability and change.

Who will participate in the Global Framework for Climate Services?

10. The Framework will build on and strengthen existing local, national, regional and global networks of climate observation, monitoring, research, modelling and service programmes, including those of WMO. It aims to achieve its goal through the enhanced role and involvement of national meteorological services and regional/global centers, as well as greater participation of other stakeholders and centers of excellence across relevant socio-economic sectors, particularly those in developing countries, Least Developed Countries (LDCs) and Small Island Developing States (SIDS).

11. To meet its objectives, the Framework would require extensive collaboration among national and local governments, agencies, non-governmental organizations, civil society, the private sector, as well as universities and research institutions around the world and outreach to communities in all socio-economic sectors benefiting from the application of climate data and information in planning, policy and practice. This outreach will be facilitated through participation of relevant organizations and institutions in coordination with governments. Implementing and operating the Framework will therefore require continuation and enhancement of the broad collaboration and partnerships, centered around these entities, which underpin and improve on its technical strengths. As such the Framework will be supported by the entire United Nations System and other organizations.

What are the Next Steps in Developing a Global Framework for Climate services?

12. Taking into account the outcomes of WCC-3, the Framework will be further developed under the guidance of an *ad hoc* taskforce consisting of high-level independent advisors, with inputs from a broad-based network of experts and in consultation with governments, partnering organizations and relevant stakeholders. The outcomes of the fifteenth session of the Conference of the Parties to the UNFCCC (COP 15), as well as the special requirements and vulnerabilities of developing countries, especially least developed countries and small island

developing States, will also be taken into consideration in further development of the Framework.

13. An Action Plan with timelines for establishment and implementation of the components of the Framework will be developed along with measurable indicators for the progress in the implementation of the framework. It will also address aspects of governance and resource requirements. The Action Plan would also address the development, deployment and transfer of technology and capacity building of meteorological services in developing and least developed countries.

How will the Global Framework for Climate Services be supported?

14. The *ad hoc* taskforce to be established to further develop the Framework following WCC-3 will examine and make proposals on resource implications related to the implementation of the Framework and the cooperation of governments, organizations, institutions and relevant stakeholders in the mobilization of resources.

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* Background paper prepared by WMO secretariat, dated 2nd September, 2009

International Group of Funding Agencies for Global Change Research

December 8, 2009

Dr. Timothy Killeen
Assistant Director for Geosciences
National Science Foundation
4201 Wilson Boulevard, Suite 705
Arlington, VA 22230
U.S.A.

Dr. Alan Thorpe
Chief Executive
Natural Environment Research Council
Polaris House, North Star Avenue
Swindon, Wiltshire SN2 1EU
United Kingdom

Dear Drs. Killeen and Thorpe,

Subject: Decisions and recommendations from the IGFA 2009 Annual Meeting,

The 2009 Annual Meeting of the International Group of Funding Agencies for Global Change Research (IGFA) was held in Paris, October 20-23, 2009. Several decisions and recommendations coming out of this meeting are relevant to the executive group and its upcoming discussions in London, in January 2010. They relate to the new management and administrative structures for IGFA; to the identification of priorities; coordination of activities; and to communications. I am writing to you in your capacity as Principals of the Belmont House conference and the upcoming Royal Society conference, to share these.

First, I am happy to confirm that IGFA members adopted the new management structure, as agreed in principle at their Mexico City meeting of 2008 and articulated at the Belmont House conference of June 2009. They embraced the establishment of the high level consultative and policy group or 'Council of Principals'. They also recognized the dual role this body will play in refocusing the consortium and orienting future activities; as well as in overseeing activities and sustaining dialogue with ICSU. Given the strategic, management and administrative challenges posed by these changes, members stressed the need for solid administrative mechanisms to support the new executive group, and made some suggestions in this regard.

I am pleased to append a summary of the key decisions and recommendations.

It is with pleasure that I also confirm the election of Dr. Tim Killeen as Chair of the IGFA consortium, effective January 2010. The members are committed to full cooperation with Dr. Killeen, as with the Executive Group.

IGFA's members represent diverse geographic regions and a range of policy and program expertise, which will add value to the new organization. Members welcome opportunities to share their insights, analyses, experience and national approaches to global environmental change (GEC). They also endorse concerted action on emerging priorities: this action will build on and complement current research support for GEC.

IGFA Secretariat, c/o Canadian Foundation for Climate & Atmospheric Sciences, Suite 901, 350 Sparks Street, Ottawa, Ontario K1R 7S8 CANADA. Phone: +1 613 238-2223 #202; Fax: +1 613 238-2227; E-mail: igfa@cfcas.org or conway@cfcas.org; Web: www.igfagcr.org

You will want to ensure relevant items from the summary are taken into account in discussions at The Royal Society in January 2010, and are provided to the executive group for consideration and action. I would be pleased to work with the executive group, as with the new IGFA Chair and Secretariat, to implement the suggestions and to ensure a smooth transition.

Yours sincerely,

Dawn Conway

Dawn Conway
Chair, IGFA

Executive Director, Canadian Foundation for Climate and Atmospheric Sciences

c.c: S. Wilson, NERC
L. Brown, NSF

Encl.

IGFA 2009 Decisions and Recommendations

Management Structure

The IGFA membership has endorsed the process for a high level consultative and policy group (or Council of Principals), as proposed by the Belmont House group and agreed in principle at IGFA's 2008 meeting. The members of this group are deemed to be members of IGFA.

- IGFA **members are committed to cooperating with the new executive and Secretariat; and to providing input on the structure and membership of the consultative and policy (executive) group** in areas such as member rotation and representation, inclusivity / exclusivity, composition and structure.
- **IGFA recommends** the following to the CoP, for consideration and refinement at its initial meeting in London, January 2010:
    - o The **name** and acronym of the IGFA partnership should be retained. (Benefits include brand recognition, contacts and credibility)
    - o The IGFA chairperson should **Chair** the Council of Principals
    - o the Director of the **EU** Environment Research Directorate should be represented on the Council of Principals
    - o The CoP should invite **representatives of special agencies** / bodies from time to time as guests to their meetings and/or IGFA plenaries (e.g. ISSC)
  - IGFA recommends a **working group** of 6-8 members, to:
    - o Feed the CoP information on priorities and cooperation arrangements; key points for action; new policy imperatives and GEC needs
    - o Interact with the new IGFA Secretariat on special issues; ensure communications
    - o Implement special tasks or analyses
    - o Assist with the organization of plenary meetings
  - The Executive Group or CoP should examine options/**structures for stable funding of GEC programmes**, including multi-year funding where feasible
  - IGFA recommends that its **next plenary meeting take place in one year**; the CoP should then to decide on the scheduling of subsequent meetings, which should be held at least every 2 years.
  - Provide incentives for member attendance at meetings, by encouraging participation in the work of the restructured IGFA partnership, stressing the relationship with the programmes and other means.

Communications Strategy

- A **communications plan must be prepared as soon as feasible**. Communication between the CoP and other IGFA members should be **proactive and reciprocal**; the communications plan should include links to the GEC programmes, e-mails to members and an up-to-date website. The website must in future be based at, and under the control of, the Secretariat.
- IGFA remains the only forum for direct dialogue between the international Global Environmental Change Programmes and research funding bodies. This must be maintained. Note: The annual meeting has been a good occasion for dialogue with the programmes, as with ICSU.
- IGFA to consider preparing a statement on the evolution of funding for GEC

Relations with ICSU

IGFA recognizes the high level role played by ICSU at the interface of policy, science and development. It appreciates the work of ICSU in ensuring exchange of ideas, evaluation of GEC programmes and development of responses to the needs of the international community. IGFA members value the improved opportunity to interact and cooperate with ICSU;

Identification and incorporation of emerging scientific issues in IGFA's strategy

IGFA members recognize the need for greater alignment of the social and natural sciences; and promotion of a coordinated initiative, aligned to emerging needs as well as to the policy and funding interests of major partners. IGFA's strategy should be informed by priorities identified by the science steering committees (SSCs) of the GCR programmes, the ICSU visioning exercise, other analyses or world developments as well as discussions at Belmont House and subsequent meetings of its Principals.

- ICSU Executive Director (or other senior person) to transfer the conclusions of the ICSU **Visioning Exercise** to the IGFA executive group.
- The Executive Director of ICSU to convey the **emerging priorities of the GEC Programmes** to the IGFA executive group.
- IGFA's Council of Principals to consider how the results of the visioning process and other exercises can feed into its strategy.
- IGFA Executive Group to define **strategic themes for Workshops** or similar focused meetings, whether dedicated meetings, or held in conjunction with IGFA plenaries. These should consider science or policy, research management, the reconnection of IGFA with development agencies, or serve as opportunities for brainstorming, etc. Proposed topics include:
  1. GEC *Research to Policy* (translation process interface; analysis of the effectiveness of interdisciplinary research) - in conjunction with ISSC & ICSU
  2. Mechanism of integrated research, including convergence of social and natural sciences and its effectiveness
  3. Framing/communication of research results; outreach to users/stakeholders
  4. Funding models/best practices for GEC research (e.g. cluster models; promotion circles, ERA-Net models; interdisciplinary networks, etc.)
  5. Adaptation/mitigation and the research needed for its sound scientific basis; Limits to adaptation
  6. Coastal cities and Global Change
  7. Regional climate impacts and research needs
  8. GEC knowledge gaps (with possible input from IPCC; GEO, etc.)

Administrative issues

The work of IGFA is demanding and members recommend that a strong Secretariat be established; they also recommend continuity in Secretariat arrangements until the new Secretariat is ready to take over (January 2010). The current Secretariat is to prepare a task list of secretariat duties and time involved, and to assist in the transition.

- Members to consider in-kind contributions to the new Secretariat, as appropriate.
- Secretariat to analyze the advantages of **reports on national GEC policies/activities** every other year. Identify 2 countries to test effectiveness of this bi-annual schedule.

Zurich, 25 October 2000

Statement on the Mode of Operation between Funding Agencies for Global Change Research Collaborating in IGFA and ICSU and International Global Change Research Programs regarding Support for Integration and Coordination of International Cooperation in Global Change Research

Appreciating the importance of global change research for better understanding and prediction of earth system processes and their interaction with humankind;

Recognizing the value of global change research as input to international conventions and for international policy-making;

Acknowledging the importance of integration and coordination of global change research at the international level and the role of the international programs in achieving this objective;

Considering the need to assure adequate stable funding for centralized operations and activities of these programs on an appropriately shared basis,

Emphasizing the importance of a two-track process through which scientific planning for global change research and development of supporting infrastructure takes place in parallel with evaluation of funding needs for such research and infrastructure;

The funding agencies for global change research collaborating in the International Group of Funding Agencies for Global Change Research (IGFA), hereinafter referred to as “the Agencies”, the International Council for Science (ICSU), and the organized international global change research programs (WCRP, IGBP, IHDP, and DIVERSITAS), hereinafter referred to as “the Programs”, parties to this Statement state as follows:

Article I

1. The Parties shall work together and make their best efforts to assure that appropriate, adequate, and stable funding is available for integration and coordination for the Programs to strengthen and extend scientific coordination and to help realize the full value of the research programs; and

2. Such integration and coordination may include, but are not limited to: establishment or major augmentation of new scientific steering committees, secretariats, and international project offices (IPO’s); activities to add value to existing integrative and coordinating activities, such as major scientific symposia and conferences; syntheses of the Programs and projects within these Programs; involvement of developing country scientists; and establishment of new regional networks;

Article II

ICSU and the Programs shall:

1. Inform the Agencies, both individually and through IGFA, well in advance of activities, especially new initiatives, that are likely to require new or additional funding with respect to integration and coordination;

2. Encourage their representatives and participating scientists to explore all possible opportunities to obtain such funding at the national level; and

3. Prepare and submit requests and/or proposals for integration and coordination activities to the Agencies and IGFA in a timely fashion and assure that such requests/proposals meet appropriate review requirements.

Article III

The Agencies shall:

1. Ensure that relevant procedures are available for ICSU, the Programs, and participating scientists to submit requests/proposals for international integration and coordination activities;

2. Keep ICSU, the Programs, and participating scientists informed regarding these procedures and any modifications thereof;

3. Identify appropriate points of contact for such requests/proposals; and

4. Exchange information and views and coordinate their policies and procedures regarding the activities defined in Article I.1 through IGFA.

Article IV

The Agencies and Programs reconfirm that the procedure for establishment of new IPOs as previously adopted by IGFA in 1996 in Oslo (Appendix A) and amended to include WCRP, IGBP, IHDP, and DIVERSITAS shall be applied to the IPOs of the Programs.

Article V

1. Cooperation between the Parties under this Statement shall be subject to the availability of appropriated funds and in accordance with the laws and regulations in the country of each Agency.

2. Any Party may withdraw from this Statement at any time by giving written notice to the others of its intention to withdraw, such notice to be given no less than 90 days in advance of withdrawal;

3. This Statement may be amended upon the initiative of any Party and by agreement of the Parties.

4. An agency or program may join at any time if they agree with all provisions in the document and upon agreement by the Parties.

Signed in .... this .... day of .... , ...
(place) (day) (month) (year)

.... , ...
(name) (organization)

Appendix A
IGFA Procedure for Seeking Support for International Project Offices (IPO's)
(Adopted by IGFA in Oslo, 1996)

1. International scientific project offices are traditionally supported through arrangements between international scientific committees and national funding entities. These arrangements should reflect clearly both the expectations and commitments of the parties concerned. These guidelines are intended to assist in achieving this objective.

2. International project offices generally require funding for:
- scientific and support staff;
- office space and equipment;
- staff travel;
- communications; and
- documentation/publication services.

Additional funding may be needed for support of scientific meetings. An overview of the functions and resource requirements for IGBP core project offices is available from the IGBP Secretariat.

3. Draft terms of reference for a project office should be developed by the international scientific committee for the project.
These terms of reference should specify:
- the tasks and responsibilities to be assigned to the office;
- the logistic requirements (in the broad categories listed above); and
- the proposed level of funding.

4. The international scientific committee should identify and approach a potential lead national funding agency. The committee and the agency should decide on an appropriate host organization for the office and define the office's operational and legal status, e.g., whether the office is to operate independently of; autonomously within; or as a component of its host organization.

5. Agencies which agree to fund or share in funding for a project office should provide such funding on a long-term basis, for at least a three-to five-year period. An agency which has a substantive interest in hosting an IPO but is able to provide only part of the overall funding needed should take the lead in developing the total resources needed through IGFA. Extensions of such arrangements should be considered and agreed well in advance of the end of each operating period.

6. Project offices (should) (often) include a core staff of two scientific professionals, a director and deputy/associate and a staff assistant/secretary. The director generally would focus on scientific activities and the deputy/associate would divide his/her time between science and management, e.g., programming, data management and budgeting. Additional scientific or support staff may be needed for specific purposes.

7. The lead national funding agency should arrange for the office to draw on the host organization's regular administrative services to support management of the office's funds and to deal with issues of staff salaries, fringe benefits etc. In addition, the host organization should assist the IPO in obtaining any governmental approvals and endorsements needed, e.g., visas, work permits, entry of office equipment, publications, etc.

8. Funding levels needed for IPO's are expected to vary, depending on the level of responsibilities and tasks assigned; the location of the office and local salary and overhead costs; currency exchange rates; and the availability of needed services within the host organization.

Appendix B
Signatories (agencies and programs)

agency/program	country	signed by	date
ICSU		Larry Kohler	18.12.2000
IGBP		Berrien Moore III.	29.11.2000
IHDP		Arild Underdal	27.11.2000
WCRP		Peter Lemke	20.12.2000
Federal Office for Scientific, Technical & Cultural Affairs	Belgium	Eric Beka	21.12.2000
European Commission	EU	Christian Patermann	7.2.2001
Deutsche Forschungsgemeinschaft	Germany	Reinhard Grunwald	23.01.2001
BMBF	Germany	Hansvolker Ziegler	13.11.2000
The Icelandic Research Council (RANNIS)	Iceland	Vilhjalmur Ludviksson	11.5.2001
Research Council of Norway	Norway	Christian Hambro	11.5.2001
Swiss National Science Foundation	Switzerland	H. P. Hertig	13.12.2000
NWO	The Netherlands	John Marks	29.11.2000
Ministry of Ukraine for Education and Science	Ukraine	R. Komirenko	8.12.2000
Natural Environment Research Council	United Kingdom	John Lawton	19.12.2000
National Science Foundation	USA	Margaret Leinen	7.5.2001

Terms of Reference for the Belmont Forum/Council of Principals of the International Group of Funding Agencies for Global Change Research (IGFA)

The Belmont Forum/IGFACouncil of Principals is composed of:

- Senior administrators from member agencies most active in the funding of global change research (Australia, Canada, the European Commission, France, Germany, Japan, the United Kingdom and the United States of America);
- Senior representatives of science funding bodies from some newly industrialized countries (presently, but not limited to, Brazil, China, and South Africa)
- Two members elected by IGFA from agencies not Council members from the above two categories to each serve for a two-year term (should they be eligible, at IGFA's discretion, for a second term?); and
- The Executive Director of the International Council for Science (ICSU).
- The Secretary General of the International Social Science Council (ISSC)

The Belmont Forum/Council is the senior consultative and policy-oriented body in IGFA. Its role is to:

- Identify strategic priorities for international collaboration on global change research (GCR) within the framework of the Belmont Challenge; and
- Identify approaches to address these priorities.

The Belmont Forum/Council will focus its activities on addressing, the overarching Belmont Challenge that faces the agencies that support global change research and the international:scientific community that conducts this research. The Belmont Challlenge is:

To Deliver Knowledge to Support Human Action and Adaptation to Regional Environmental Change.

The Belmont Forum/Council recognizes that to address this challenge require regional and decadal prediction, advanced observing systems, and inclusion of social sciences; and recognition of the synergy of multiple stressors, including extreme events, for, in particular:

- **coastal zones;**
- **water cycle and water resources;**
- **ecosystem services - food security;**
- **carbon cycling; and**
- **most vulnerable societies.**

The Belmont Forum/Council of Principals will meet at regular intervals, at least annually and, initially, more frequently. The meetings will be oriented to concrete action and measurable outcomes to address the Belmont Challenge.

The activities of the Belmont Forum/Council will be directed to, in cooperation with ICSU, joint activities leading to early-phase engagement by scientists and funders on setting international strategies and assigning priorities, leading to improved co-design and alignment of international research. The Belmont Forum/Council's actions are expected to complement and be underpinned by the ongoing actions of the full IGFA membership (including sharing of GCR information and best practices; dialogue with international GCR programmes and intergovernmental GCR offices; and coordinating collaborations or funding partnerships in theme areas).

These actions will be directed to development of an integrated, multinational plan for short-term and long-term projects – a RoadMap for Addressing the Belmont Challenge.. This plan would constitute the core of IGFA's strategy and the foci of its actions would include:

- identifying emerging needs or issues;
- co-designing one or more initiatives of global scope;
- developing a coordinated approach and consensus on action;
- developing ways to communicate (with whom – the public, scientists, others?) more vigorously/broadly??; and
- maintaining dialogue with appropriate decision makers on GCR issues.

The role of the full IGFA membership will not change (see http://www.igfagcr.org/about.html), but members will be encouraged to align their actions with, and provide input to, the development and implementation of the above plan. Input to development of this plan, and to other issues to be addressed by the Belmont Forum/Council, will be invited from the full membership of IGFA. Full IGFA meetings will normally take place every two years, but additional meetings could be convened by the Co-Chairs (see below) in response to special needs.

(Should a statement regarding members' responsibilities be inserted here along the following lines: "Members are encouraged to consult with and to represent, whenever possible, other national funding agencies, especially those with leadership roles in areas closely related to IGFA's foci.")[Personally, I would add this because it encourages broader engagement and in some cases other agencies are leads for key infrastructure required to support the Belmont Challenge goals, but no doubt it will be a point of discussion at the meeting.]

The Belmont Forum/Council will elect Co-Chairs from among the core members of the Belmont Forum/Council with each Co-Chair to serve for a two-year period on a rotating basis (should the Council have the authority to re-elect one or more of the Co-Chairs for a second term?) One of the Co-Chairs will serve as Chair of the full IGFA. The Chair is expected to provide overall leadership for IGFA; bring emerging new issues to the agenda; propose initiatives for priority setting; and make proposals for achievement of common goals (should a specific role also be assigned to the other Council Co-Chair?).

The Chair's institution will also support and host a small Secretariat for the Belmont Forum/IGFA Council of Principals. This Secretariat will chair the Belmont Forum/IGFA Council of Principals Working Group, comprised of one senior level manager appointed to represent each Belmont Forum/Council member.

As noted above, IGFA will meet biannually. Both the Belmont Foum/Council and full IGFA meetings will be scheduled as much as possible in conjunction with major meetings of international bodies concerned with GCR. The Belmont Forum/Council may invite representatives of other bodies to participate in its meetings and other activities as appropriate.

During the period between the biannual plenary meetings, the focus and momentum of the organization will be maintained through vigorous proactive and reciprocal communications activities, through the meetings of the Belmont Foum/Council of Principals, and through occasional meetings drawn from the larger membership around specific themes (keep in mind that these meetings could include academic scientists designated by ICSU, since they are a member of the Belmont Forum/Council).

Proposed Terms of Reference for the Working Group of the Belmont Forum (BF)/ International Group of Funding Agencies for Global Change Research Council of Principals (IGFA-CoP)

*(Terms of Reference for the "Belmont Forum/**Council of Principals of the International Group of Funding Agencies for Global Change Research (IGFA)" attached for reference (Annex I))***

The Working Group is composed of:

- Senior working level managers who have been appointed by their Belmont Forum member to coordinate their organization or countries' contribution to the Belmont Forum/ IGFA-CoP.
- Two members of the group will co-Chair the group on a rotating basis. Rotation will follow the co-Chairs of the Belmont Forum/ IGFA -CoP

The Working Group is the Working Level Implementation and Coordination body of the Belmont Forum/ IGFA-CoP In that capacity, core tasks of the Working Group will include:

- Implementing measures toward addressing the "Belmont Challenge."
- Acting as a point of contact for their respective Belmont Forum/IGFA-CoP member in taking forward actions and engaging with external stakeholders .
- Regular communication [to whom?] on Agency and National Initiatives toward the addressing the Belmont Challenge and Global Environmental Change more broadly
- Coordination of National or Agency representatives working on collaborative research actions related to Belmont Forum and IGFA, and reporting on progress to Belmont Forum
- Planning, as necessary, for Belmont Forum, Working Group and broader, biannual IGFA meetings, including hosting meetings on a rotating basis.
- Providing content and commenting on content developed for the newsletter, the web site, and other communication materials

Working Group members are encouraged to work across their organization, nationally, and regionally where appropriate and possible, to enhance the impact and effectiveness of the Belmont Forum and IGFA.

A primary function of the Working Group is to drive progress on actions between Belmont Forum meetings. Therefore, its primary mode of operation will be through mechanisms other than formal meetings, e.g. correspondence, teleconferencing, and focused sub-meetings around specific actions.

However, in order to coordinate progress of actions towards the Belmont Challenge as a whole, the Working Group will also meet regularly, at least annually, and, initially, more frequently. In recognition of the global distribution of its members, every effort will be made to enable participation in these meetings through electronic correspondence, voice and video conference whenever possible. When meetings are necessary, effort they will be coordinated around other international meetings in which Working Group members would, as a regular part of their responsibilities participate.

The Working Group will have two Co-Chairs that will rotate with and identified by the Co-Chairs of the Belmont Forum/IGFA Council of Principals.

AnnexI

Proposed Terms of Reference for the Belmont Forum/Council of Principals of the International Group of Funding Agencies for Global Change Research (IGFA)

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