# Future Earth – Research for Global Sustainability

# Draft Research Framework

22 November 2012

*Future Earth is a 10-year international programme on integrated Earth system research for global sustainability. The goal of Future Earth is to develop the knowledge required for societies worldwide: to face challenges posed by global environmental change and to identify opportunities for a transition to global sustainability.*

*This Research Framework provides the initial strategic directions and approaches to research under Future Earth. It introduces Future Earth and its goals, and provides a conceptual framework, a set of design criteria which will guide Future Earth research, and a preliminary set of research themes and cross-cutting capabilities.*

This draft framework is a working document of the Future Earth Transition Team, an international group consisting of researchers from the natural sciences, social sciences, and humanities, as well as from international organizations, research funders and business, in the spirit of co-design. It is intended as a consultation document and a starting point for the process of co-designing Future Earth and its research themes, rather than a finished product. Future Earth is expected to develop and evolve through a wider consultation process and as the transition is made to fully operational governance.

**Working draft of the Transition Team for Future Earth**
**http://www.icsu.org/future-earth/who/transition-team**

**Not for broad circulation**

**Why Future Earth?**

Human activities are altering the Earth system and impacting the environment in ways that threaten wellbeing and development. We have entered a new geological epoch, the Anthropocene (Crutzen 2002), in which human activities significantly impact many global processes in the Earth system, and together with natural variations, are leading to global environmental changes. At the same time human knowledge and ingenuity in an increasingly interconnected world of research offers many possibilities for unprecedented innovation to respond to these changes and to create new opportunities for individuals, communities, firms and countries to thrive.

Global environmental changes have regional and local impacts, including on access to, quality and use of air, water, land, and marine and terrestrial ecosystems. The cross-scale interactions between human activities, large scale changes in the Earth system, and local impacts have important implications for human development. They suggest that global sustainability is a prerequisite for human wellbeing at local as well as global scales and help define the sustainability challenges facing society. For example, knowledge-based solutions are needed to provide food, water, materials and energy security for all, to allow humanity to not only survive but thrive in the context of economic development, population growth, climate change and continued loss of biodiversity.

The challenge of achieving a transition to global sustainability is not only large in scale - it is also urgent. There is growing evidence that the climate is changing and critical environmental services are degrading and that there are risks of crossing critical tipping points in the Earth system. These changes can trigger potentially catastrophic and irreversible implications for human societies. There are also many important, unanswered questions relating to the global environmental change, sustainability and the basic functioning of the Earth system that need to be addressed.

Evidence to date indicates little progress is being made towards sustainability. UNEP's recently published Global Environmental Outlook-5 (2012a) assesses the state of the environment in different regions, for different sectors and for the world as a whole, and concludes that we are not moving towards sustainability, with only 3 of 90 indicators showing significant improvement. Development indicators have shown some improvement, yet about a billion people are reported as still poor and hungry (UNMDG, 2012) and many more experience chronic threats to their livelihoods, health, and well-being.

At Rio+20, the nations of the world agreed to develop Sustainable Development Goals that integrate environmental and development indicators to set targets for the future and discussed other options and opportunities for environmental stewardship and equitable development. There are calls for science to provide the knowledge base for these and other efforts to build a sustainable, just and prosperous future for current and future generations.

The international research community has a number of organizations and networks that promote coordination and collaboration to understand the causes and consequences of global environmental change and options for sustainable development. Notably, these include the existing Global Environmental Change programmes – the World Climate Research Programme (WCRP), the International Geosphere-Biosphere Programme (IGBP), Diversitas, the International Human Dimensions Programme (IHDP) and the Earth System Science Partnership (ESSP). Together with their projects, these programmes have facilitated progress towards 1) understanding and responding to global environmental change; 2) creating important networks of researchers and connections to decision makers, and 3) developing research strategies, but have not addressed the full range of challenges or created a fully integrated set of activities. The serious and urgent challenges the Earth and its inhabitants now face demand a step-change up to even greater understanding and solutions. A renewed, more integrated, and more international effort is needed to connect these research activities, seek new resources for priority questions, and produce solutions together with key societal actors that include governments, business and civil society. This call has been echoed in the Earth System Visioning process for the next decade of Earth system research (ICSU/ISSC, 2010); the science strategy development by the Belmont Forum (2011); by UN agencies such as UNEP and UNESCO; and through demands for a new contract between science and society made in recent reports and international conferences, including Planet under Pressure and Rio+20 (e.g., DeFries et al., 2012; Richardson et al. 2009; Planet Under Pressure 2012; UNCSD 2012; UNEP 2012b).

**Future Earth** is the response to the need for international, integrated, collaborative and solution-orientated research to respond to the challenges of global environmental change and sustainable development.

**Future Earth** is conceived as a 10-year programme, that builds upon Earth system science and brings together global environmental change researchers and projects to further develop interdisciplinary collaborations that address critical questions, particularly those that seek to understand the changing natural and social systems, observe, analyse and model the dynamics of change and especially human-environment interactions; provide knowledge and warnings of

risks, opportunities and dangers; and define and assess strategies for responding to change, including through the development of innovative solutions. It provides the opportunity for scientists from today's broad range of international programmes, projects and initiatives to work together under a unifying framework.

**Future Earth** research will contribute new, solution-orientated insights and knowledge to existing and emerging global sustainability challenges facing the world. The following 10 questions represent some of the challenges where Future Earth research is expected to make a major contribution:

- How can humanity feed a growing world population within sustainable boundaries of the Earth system?
- How can governance be aligned with the opportunities for global sustainability?
- What risks is humanity taking in the Anthropocene, from negative implications on development to crossing tipping points with catastrophic implications for human societies?
- How can the world economy and available technologies be transformed to stimulate innovation processes that foster sustainable development?
- In a rapidly urbanizing world, how can humanity design and sustain liveable and sustainable cities?
- How can humanity succeed in a rapid global transition to a low-carbon economy that secures energy access for all and preserves the remaining biodiversity on Earth?
- How can societies adapt to the social and ecological consequences of warmer world, and what are the barriers, limits and opportunities in adaptation?
- How can natural capital, ecosystem services, and environmental processes on Earth be shared in a fair way among all citizens in the world?
- What lifestyles, ethics and values are conducive to environmental stewardship and human wellbeing and how might these evolve to support a positive transition to global sustainability?
- How does global environmental change affect poverty and development, and how can the world eradicate poverty and create rewarding livelihoods while achieving global sustainability?

There are many areas where Earth system research can contribute to better understanding these challenges and help identify solutions. For example, observing and forecasting the dynamics and interactions of Earth system components, including social elements, will provide the knowledge needed to assess the state of the planet, understand the risks and opportunities

in where we may be heading, and explore alternative scenarios for the future. Understanding the relationships between biological diversity and ecosystem function will play a critical role in sustaining the ecosystem services provided by nature (e.g. healthy soils, clean water, fresh air etc); analysing the effectiveness of different response options to environmental change, and identifying the longer term social transformations associated with the responses, to help identify pathways to sustainability.

**Future Earth** intends to take major steps forward in several ways that add value to existing research activities, including:

*Co-design of research and activities:* Future Earth aims to close the gap between environmental research and current policies and practices. Future Earth invites the broad community of researchers working within the natural sciences, social and economic sciences, engineering and humanities to engage in developing knowledge that is co-designed and co-produced with those who use research in governments, business, and civil society. Such co-design means that the overarching research questions are articulated through deliberative dialogues among researchers and diverse societal actors to enhance the utility, transparency, salience and support for the research.

*Increased international and regional emphasis:* Future Earth prioritises research that requires international cooperation to succeed because the research and solutions are difficult to implement at only the national level. In Future Earth, international research must be inclusive, involving researchers from the full range of countries and building capacity where needed, especially in the least developed countries. Future Earth also recognizes the added value of regional research nodes and collaborations where common questions, challenges, projects and solutions are best designed and implemented within and between clusters of countries and among researchers that share common problems, regional concerns, and cultural perspectives.

*Decision support and communication:* Future Earth intends to deliver a step-change in making research more useful and accessible for decisions and solutions that can be made by governments, business and civil society regarding environmental change and sustainable development. In addition to the principle of co-design, this means that Future Earth should use best practices in understanding user needs and understanding of the research, making research accessible to all parties, communicating uncertainty, developing useful tools for applying knowledge, resolving conflicts, respecting and including local knowledge and supporting innovation.

(A more complete list of Future Earth design and delivery principles is presented in Annex 1 to this document.)

Future Earth will also respond to the research needs identified by major global and sectoral assessments such as the Intergovernmental Panel on Climate Change (IPCC 2007), the Millennium Ecosystem Assessment (2005), and the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD, McIntyre et al 2009). The new Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) and the Assessment of Assessments (AOA) on the oceans are other important opportunities for global environmental change researchers to contribute and collaborate through the mechanisms and networks of Future Earth.

## A Conceptual Framework for Future Earth

*Overall framing*

The conceptual framework for Future Earth, which guides the formulation of its research themes, takes as its starting point the recognition that humanity is an integral part of the dynamics and interactions of the Earth system and must operate within its boundaries. From the local to global scales, human development is influencing environmental processes; at the same time that human well-being depends on the functioning and stability of these processes. The overall framing of Future Earth focuses on social-environmental interactions and their implications for global sustainability. The conceptual framework is illustrated in Figure 1 and described below.

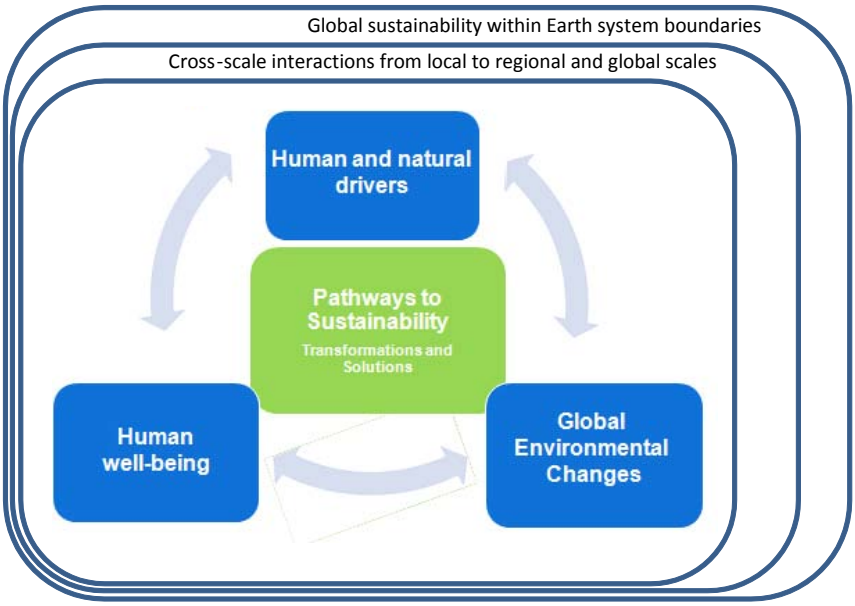


**Figure 1.** Schematic of the Future Earth conceptual framework. Social and environmental drivers generate global environmental changes in the coupled Earth system, with implications for human wellbeing. Understanding Earth system interactions, risks and opportunities, can open avenues for transformative pathways to global sustainability. To understand social-environmental interactions and solutions requires new integrated science that addresses cross-scale interactions and social-environmental dynamics in the coupled Earth system. To answer the most pressing questions humanity is facing in the context of the Future Earth conceptual framework, will require scientific approaches that address the grand challenges of (i) improving Earth observations and (ii) improving ability to forecast global changes, (iii) advancing strategies for confining risks and understanding thresholds, (iv) advancing new knowledge on how to respond to unavoidable change and (v) advancing innovations in support of transitions to global sustainability.

*Understanding complex drivers of change*

Human activities and development generate environmental impacts at the local, regional and global scales that interact with natural drivers of change. Global environmental change is a result of complex social-environmental interactions between components of the Earth system, where local to regional impacts on the environment can generate feedbacks, with unexpected outcomes.

*Human wellbeing and global sustainability*

Human wellbeing depends on ecosystem functions and services, ranging from food, water, energy and materials, which are intrinsically linked to the sustainability of the Earth system, and the functioning and interactions among its components; the biosphere (land and oceans) hosting ecosystems and biodiversity, the atmosphere (the climate system, weather patterns, ozone layers), the geosphere (natural resources and material flows) and cryosphere (ice sheets providing climate regulation and ecological habitats).

Impacts of global environmental change on people and societies in turn depend on their social and environmental vulnerabilities and resiliencies. Understanding impacts on societies thus requires knowledge of the resilience of local to regional ecosystems and societies, to both natural variability and human-induced changes in the global environment.

*Responding to change and exploring pathways to global sustainability*

Humans respond to impacts of global environmental change through a wide spectrum of strategies for mitigation, adaptation, innovation and transformation. The way societies respond to observed impacts or forecasts of environmental change depend on a complex mix of political, cultural, economic and moral dimensions. Knowledge plays a critical role in informing all aspects of societal change, both in terms of providing insights of risks and opportunities, and in providing new solutions for adaptation and transformation in the face of global environmental risks.

Human responses can reduce the risks of environmental change and define the future trajectories of human development. Achieving global sustainability will require fundamental, innovative and long-term transformations – and there may be a range of options or trajectories which face society, and provide the next chapters in human development.

*Cross scale interactions are critical*

While the conceptual framework emphasizes the Future Earth focus on global environmental change and global sustainability, also highlights cross-scale interactions and feedbacks across its components.

*Three major research challenges*

Future Earth will provide new knowledge from integrated Earth system research that informs societies on the integrated social-environmental challenges outlined in the conceptual framework. Three major thrusts of research arise from this framework.

*Firstly*, understanding how planet Earth and the world are changing in the Anthropocene. This will require intensified and novel research on mapping, understanding and projecting global change processes and interactions between social and environmental change across scales.

*Secondly*, Future Earth will advance research on impacts on human wellbeing, peoples and societies, through integrated social-environmental research that connects research on livelihoods, economics, ecosystems and development with that on global environmental change.

*Thirdly*, Future Earth will focus on solution-orientated science that enables societal transitions to global sustainability. This will include research that advances strategies of how to anticipate, avoid and manage disruptive global environmental change (from the ICSU/ISSC Visioning strategy of science for confining the risk of regime shifts). Future Earth will also advance science on various response strategies. This will involve research on what institutional, economic, social, technological and behavioural changes can enable effective steps toward global sustainability, and on how these changes might best be implemented; research on long-term transformative pathways and scenarios (e.g., how can a transition to a low carbon future be achieved); research on innovation pathways, coupled with sound mechanisms for evaluation, in developing technological, policy, and social responses to achieve global sustainability.

Overall, Future Earth will advance our understanding of the interrelationships between human development, wellbeing and global environmental change, and provide analyses of current trajectories and forecasts of global environmental change under different development future scenarios.

*The proposed research strategy below* combines the global challenges arising from the Future Earth conceptual framework with the on-going research of global environmental change programmes and other partners.

**Proposed Research Strategy**

At the simplest level, Future Earth must answer fundamental questions about ***how and why the global environment is changing, what are likely future changes, what are the implications for human development and other species, and what the opportunities are to reduce risks and vulnerabilities, enhance resilience, and create transformations to prosperous and equitable futures.*** Future Earth will show how this knowledge can inform and support actions for sustainable development that enhance human wellbeing.

Future Earth research will be organized around three broad and integrated research themes: *Dynamic Planet*; *Global Development*; and *Transformations toward Sustainability*. These themes are designed to address the most urgent environmental challenges facing humanity through research that demands basic and applied, international and interdisciplinary approaches. They respond to the need to understand how the Earth system is changing, and the need for knowledge to support human development priorities and transformations that move us towards sustainability. The proposed research themes and questions are intended for discussion and broad consultation, as well as user engagement and research planning in co-design mode. The themes will be addressed by a number of existing and fundamentally new research projects, with some projects contributing to more than one research theme. The science within the research themes will be underpinned by a set of crosscutting capabilities that are necessary to carry out the research agenda. In many cases the required crosscutting capabilities—such as observations, models and theoretical frameworks—will be brought into the initiative through partnership arrangements.

Each research theme will address a series of research questions that build on the overall conceptual framework of Future Earth. Examples of research questions – some already addressed within and across existing global environmental change projects – are provided below and the community is encouraged to suggest other high priority questions.

The research themes build upon and integrate existing research agendas and science plans, but also incorporate new areas of investigation. The Science and Technology Alliance for Global Sustainability, scientific sponsor of Future Earth, includes organizations such as ICSU and ISSC that bring together agendas and science plans developed by the scientific community in a bottom-up process. It also includes the more directed programmes of organizations, such as UNEP and UNESCO, and national research funding perspectives. For Future Earth to succeed,

the enthusiasm of the scientific community and the priorities of international organizations need to be combined into a common research agenda supported by projects that address major questions of scientific and policy significance. The co-design and co-production process also offers new opportunities for funders to partner in implementing this agenda through existing and new mechanisms. Thus, the research themes and the example questions proposed by the Transition Team are but the first step in a multi-year process to design, adapt, and implement Future Earth research projects to solve the most pressing challenges of global environmental change and sustainable development.

***Research Themes***

Research themes constitute the highest organisational units for research under Future Earth, and will function as broad platforms for strategic and integrated Earth system research. The themes are broad, and call for collaboration across a range of research areas and disciplines. For example, understanding and modelling the state and dynamics of the planet rests on fundamental work in atmospheric and ocean science, hydrology, ecology, and biogeochemistry. Understanding how to achieve long term transformations towards sustainability will draw on research in areas such as law, international relations, engineering, economics, geography, ethics and psychology.

All the themes thus involve collaborative, transdisciplinary and integrative research across scientific disciplines. Together, the combined themes provide a concise and comprehensive synopsis of development options and sustainability. However, to realize Future Earth's full potential, specific integration efforts are required to bring together the knowledge generated by the individual themes. Thus, the science within the IRTs will be supported by a set of cross-cutting capabilities that are necessary to carry out the broader research agenda, and will often be provided through partnerships with initiatives outside Future Earth.

The proposed themes below were developed by the Transition Team and have already been revised in response to initial consultations. Supported by the set of crosscutting capabilities, these themes propose an initial structure for the implementation of Future Earth. There are many options for organizing research priorities and themes – for example around basic human development needs (water, food, energy) or by Earth system components (climate, land, oceans). The research themes proposed below are designed to 1) build on the agenda set out by the ICSU/ISSC Visioning process and Belmont Forum 2) provide opportunities for existing GEC projects to seamlessly associate with Future Earth and 3) respond to new and urgent calls for research to inform development and to identify the social, technical, economic and other transformations towards sustainability.

| | *Proposed Research Themes* |
|---|---|
| 1 | **Dynamic Planet**: Observing, explaining, understanding, projecting earth, environmental and societal system trends, drivers and processes and their interactions; anticipating global thresholds and risks. |
| 2 | **Global development:** Providing the knowledge for sustainable, secure and fair stewardship of food, water, biodiversity, health, energy, materials and other ecosystem functions and services. |
| 3 | **Transformation towards Sustainability**: Understanding transformation processes and options, assessing how these relate to human values, emerging technologies and economic development pathways, and evaluating strategies for governing and managing the global environment across sectors and scales. |

**Table 1.** Proposed Research Themes for Future Earth.

## The rationale for the proposed themes

The proposed conceptual framework for Future Earth describes an interconnected system in which both natural systems and human activity are driving changes in the regional and global environment with significant implications for human wellbeing. Changes in wellbeing – such as incomes and health – are affected directly by societal and natural drivers. They can also alter these drivers, for example as income and dietary changes alter energy use, land use, and emissions. Finding solutions and identifying transformations that reduce the risks of negative changes and enhance positive outcomes are central to the conceptual framework and can focus on all or any of the three other elements, altering trajectories of human drivers, mitigating global environmental change, or fostering human wellbeing.

Based on this simple schematic of linkages between natural and human systems the research themes are designed to deliver knowledge and solutions with three important goals. First is to provide an understanding of how the Earth and human system are changing in response to natural and social drivers and how these changes result in global environmental change and risks (the Dynamic Planet research theme). The second goal is to apply this understanding to the challenges of stewarding resources in support of sustainable development and human well being, responding to current needs for science to provide solutions in the areas of food, water, health, energy, materials, disaster risks, and ecosystem services (The Global Development research theme). The third theme addresses the longer-term options and pathways to transform the earth and societal system towards sustainability – research that explores

fundamental changes in human values, technologies, infrastructures, economic systems and governance that are needed for humans and other species to survive and thrive (the Transformation towards Sustainability theme).

**Descriptions of the themes**

**1. Dynamic Planet**: *Observing, explaining, understanding, projecting earth, environmental and societal system trends, drivers and processes and their interactions; anticipating global thresholds and risks.*

The Dynamic Planet research theme will provide the knowledge needed to understand observed and projected trends in the Earth system, including both natural and social components, variations and extremes, and interactions globally and regionally. It encompasses research questions and projects that seek to observe, monitor, explain, and model the state of the planet and its inhabitants and possible future trends in global environmental change including the potential for abrupt change and potential thresholds in the Earth system. The Dynamic Planet research theme has a particular goal of providing the science base for reports and assessments of the state of the planet and providing early warnings of extreme events, vulnerabilities, and thresholds.

The global change research community has an important role to contribute to knowledge about our changing planet – understanding how and why the planet is changing and forecasting likely futures. Working with other critical partners (such as United Nations and national data and information agencies), the research community provides observations, models, analyses and projections that help society and decision-makers understand past, present and future changes and interactions in global climate, air quality, land, water, oceans, ice cover, ecosystems and biodiversity, and the natural and human drivers of environmental changes. The human drivers include production and consumption, population dynamics, trade, technology and urbanization, as well as the values and policies that alter these drivers.

Assessments such as the IPCC and MEA, the periodic GEO reports from UNEP, and annual reports of organizations such as the World Bank, UNDP and FAO make extensive use of such knowledge but also reveal important gaps in geographic and temporal observations, understanding of system processes, and confidence in projections. This knowledge also contributes to establishing and monitoring indicators and objectives such as the Millennium Development Goals (MDGs) and future Sustainable Development Goals (SDGs). The information in reports is widely used to build awareness about global environmental change, to

inform international and national discussions and negotiations about environment and development, and to guide action on environmental issues.

Observing and modelling the state and future of the planet has been a core concern and major contribution of global change programmes such as IGBP and WCRP, and Future Earth hopes to draw on and add value to the research expertise of existing international projects that focus on understanding processes, trends and projections of change (e.g. CLIVAR, GEWEX, SPARC, CliC, GCP, bioDISCOVERY)[1]. As an example, the annual assessments of the state and trends of the carbon cycle provided by GCP have become an important input into policy discussions about climate change. Model inter-comparison projects such as CMIP, EMF and AGMIP provide critical steps in improving projections and input into major assessments such as IPCC. Accurately observing and modelling our dynamic planet also relies on the fundamental Earth, ecological and social science undertaken by global environmental change projects and their partners (e.g. Biogenesis, IGAC, ILEAPS). The contributions of researchers to understanding the planet was well illustrated in the presentations at the 2012 Planet Under Pressure conference and Rio Science and Innovation Forum. The importance of observing and understanding both natural and human drivers and impacts of global environmental change was highlighted at these events.

The aim is to build on these significant achievements through more integrated, detailed, cross-scale, and user-responsive research that includes co-design and partnering to maintain and enhance observation and modelling systems and improve basic understanding of how systems function. This approach advances understanding of Earth system interactions, adding new information and partners that fill gaps in space and time to track the state and targets for ecology, biodiversity, and human development, emerging pollutants, human views, activities, and impacts. For example, projects associated with the Dynamic Planet theme can make important contributions to discussions about sustainable development goals (SDGs) and to the on going assessments of IPCC, IPBES and other policy relevant synthesis and reporting efforts.

Global environmental change researchers have provided important forecasts and warnings of risks associated with extreme geophysical events, social vulnerabilities to environmental change, newly emerging risks (such as the ozone hole or ocean acidification), critical zones, and

[1] ***The Transition Team has provided some examples of how existing projects might contribute to the proposed research themes and sample questions but these are only tentative and await consultations and inputs from projects that could expand and revise these examples to better reflect how they would wish to contribute to Future Earth.***

potential tipping points and thresholds in the earth system. Large losses from geophysical disasters and the risk that human activity in the Anthropocene will trigger rapid or irreversible changes in the Earth system highlight the need for research to understand the risk of tipping points, and explain, map and predict vulnerability and human and ecological resilience to extreme events and abrupt change. Future Earth will place a particular emphasis on research related to the development of early warning systems for abrupt change that would be of use to decision makers, resource managers and business. Climate change is only one focus of such warning systems, which might also anticipate and warn of rapid changes in forest cover, biodiversity, or water quality (e.g. GLP). A focus on vulnerability and resilience within this Future Earth theme is an excellent opportunity for the disaster risk reduction research community (e.g. IRDR) to come together with global environmental change researchers - especially those who focus on forecasting extreme events and anticipating thresholds and those who work on vulnerability and adaptation (e.g. PROVIA). Historical analysis also offers important insights into past global environmental changes and their interactions with social systems and ecological regimes (e.g. AIMES).

Although Future Earth focuses on research with an international scope, the shared challenges of particular places and regions are also a relevant priority. Within our planet, some regions, people and ecosystems are more vulnerable than others to global environmental change because they are located in places where changes are most extreme, where populations are concentrated or poorer, or where the Earth system is closer to thresholds.

Global environmental change programmes have focused attention on particular regions and biomes that play important roles in the Earth system or are particularly vulnerable to environmental change (e.g. MAIRS). These include the Arctic, Antarctic, Island and Mountain ecosystems which are vulnerable to global warming that increases temperatures, melts ice, releases methane, causes sea levels to rise, and alters ecosystems —and are also important controls on the atmospheric and oceanic system (e.g. CliC). Another region or biome of concern is the tropical forests, which exert an important influence on global and regional biogeochemical and hydrological cycles and are reservoirs of biodiversity and cultural diversity under pressures from agriculture, logging, mining and infrastructure. Deltas are another critical zone. In the human realm cities can be seen as another critical zone for research and global environmental change (e.g. UGEC).

What types of research questions and projects will address the Dynamic Planet research theme? The Future Earth Transition Team identified the following example research questions

to illustrate potential research priorities that can be addressed by current, updated or new collaborative international efforts:

- What are the states and trends of key environmental components such as biodiversity, climate, soils, cryosphere, biogeochemistry, air quality, hydrology, and oceans, and in the human drivers of change and the social foundations of sustainable development such as population, consumption and technology, wellbeing, equality, health, education, human security? How and why do these vary across time, space, and social context?
- What approaches, theories, and models allow us to explain the functioning of Earth and socio-ecological systems, understand the interactions between them, make projections for the future, and anticipate critical thresholds?
- What are the risks of crossing regional to global thresholds and planetary boundaries and inducing tipping points and social-environmental crises due to global environmental change?
- What kind of integrated global and regional observing systems and data infrastructures are needed to document and model the coupled Earth system and the anthropogenic drivers of change? Can we develop reliable monitoring systems, models and information systems and services that anticipate and provide early warnings of large scale and rapid change?
- What can be understood and anticipated about the condition and future for critical zones and biomes such as coasts, tropical forests, or polar regions?

In summary, the Dynamic Planet research theme brings together existing strengths of global environmental change researchers in continuing and in new efforts to understand, document and anticipate how the Earth system and its socio-ecological interactions are changing and recommits the research community to communicate this knowledge to the full range of stakeholders. In the spirit of co-production Future Earth would also seek to identify and enhance partnerships that bring resources and expertise to monitoring and understanding how the planet is changing, including those of governments, the business and civil society.

**2. Global Development:** *Providing the knowledge for sustainable, secure and fair stewardship of food, water, biodiversity, health, energy, materials and other ecosystem functions and services*.

The research theme on Global Development will provide the knowledge needed to understand the links between global environmental changes and human well-being and development and will provide relevant knowledge for sustainable, secure and fair stewardship of food, water, health, energy, materials and other ecosystem services. In proposing this major research

theme, Future Earth signals a new contract between science and society that focuses global environmental change knowledge on the most pressing problems of human development – providing safe and adequate food, water, energy, settlements and other ecosystem services for all without degrading the environment or destabilizing the earth system. This theme focuses on the more immediate challenges of sustainable development in contrast to the third theme, which addresses more fundamental and long-term transformations that are needed for global sustainability.

Global environmental change affects human wellbeing and social and economic development, just as development strongly influences the global environment. Human development in the Anthropocene is closely linked to the management of land, water, energy, materials, biodiversity and other natural resources; agricultural, forest and marine ecosystems; and the atmosphere and ocean. The international community has called for science to contribute to sustainable development agendas and most development institutions now recognize the importance of environmental research in areas such as food, water, ecosystems and energy. Organizations such as FAO, WHO, UNDP and UNEP have a broad interest and expertise in environment and development. Future Earth will add value with research that shows how global environmental changes (e.g. in climate, air quality, biodiversity, oceans or soils) link to and undermine development, how development efforts can in turn add to global environmental problems, and how global environmental change relates to issues of human security, gender equity, indigenous cultures and justice.

In combining international expertise, data and insights from both the global change and the development communities, this theme will be particularly responsive to societal needs; it will contribute to a better understanding of the human dimensions of environmental change, and it will innovate in areas such as agriculture, water reuse, and economic and technological opportunities.

The Global Development theme builds on some of the efforts of the GEC Earth System Science Partnership (ESSP with its projects that include food, water, and health) and of other organizations in the Future Earth Alliance such as UNEP, UNU and UNESCO. For example, research on climate change risks to food systems has revealed many opportunities for reducing the vulnerabilities of tropical and temperate agriculture to climate change and for mitigating greenhouse gas emissions in the food system (e.g. GECAFS/CCAFS). Research-based innovations in governance and technology have shown how to increase water supplies across society through water reuse, markets, legal rights, behavioural change and social support systems (e.g. GWSP, UNESCO-IHP). Knowledge about the environmental impacts and

distributional effects of different energy sources can inform decision making about investments, locations and policies for providing safe and secure energy (e.g. GEA). Research shows that air pollution and the incidence of vector-borne diseases are influenced by interactions between climate variability, health interventions, infrastructure, and poverty, and that numerous points for intervention exist (ecoHEALTH, GECHH).

Extreme events pose significant threats to development, especially as the risks shift as a result of climate, land use and other global environmental changes. By better connecting global environmental change research to the disaster risk reduction research community and their stakeholders Future Earth can inform efforts to reduce disaster vulnerabilities and damages and plan for safer settlements. The climate community has much to contribute in terms of forecasting extreme events and providing climate services, and social scientists and engineers have knowledge essential to understanding changing patterns of vulnerability and options for reducing it (e.g. WMO Global Framework for Climate Services, GFCS).

An increasingly globalized trading system means that products are consumed in complex supply chains that transfer embodied carbon, water, mineral resources and waste around the world, with implications for the global environment, wellbeing and human security that can be addressed through, for example, policies and governance interventions (e.g. GCP, GECHS). Global commodity chains and price volatility also can translate climate or disaster impacts in one region to many others, contributing to new types of vulnerability (e.g., wheat price shocks in the global food supply chain following regional or local drought) that call for more innovative approaches to enhancing resilience to shock. The political and social driving forces for land use change also can have distant origins in commodity trade and conservation policies that have, for example, moved deforestation from one region to another (e.g. LUCC/GLP) or resulted in new demand for biofuels. Biodiversity is a key to development, in that it provides the basis for fully functioning ecosystems, important for human well-being and economies, with the loss of biodiversity shown to undermine development (e.g. freshwaterBIODIVERSITY, agroBIODIVERSITY). Increasing scientific evidence shows that stewardship of the atmosphere, biosphere, land and water is key to avoiding disastrous risks from global environmental change.

What types of research questions and projects can contribute to the Global Development research theme? The Future Earth Transition Team identified the following example research questions to illustrate potential research priorities that can be addressed by current, updated or new collaborative international efforts:

- What are the patterns, trade-offs and options for equitable and sustainable use of resources and land, and how can we ensure sustainable access to food, water, clean air, energy and materials for current and future populations?
- What are the implications of climate change for food, water, health, human settlements, and ecosystems? How can climate services and disaster risk reduction reduce these impacts and facilitate adaptation?
- What are the links between biodiversity, ecosystems, human wellbeing and sustainable development?
- How socially and environmentally effective, efficient and equitable are alternative approaches for conceiving, measuring and implementing development projects?
- What options are available to provide energy for all with reduced environmental impacts, and what are the social implications of these energy choices?
- How can the business and industrial sector contribute to development, prosperity and environmental stewardship through the management of their production and supply chains?
- How does global environmental change affect distinct groups in society such as Indigenous people, women, children, subsistence farmers, business, the poor or the elderly? How does their environmental knowledge contribute to solutions for sustainable development?

In summary, the Global Development theme brings together global environmental change researchers in existing and new partnerships with the development community and other stakeholders to identify and solve the basic needs for human development and security.

**3. Transformation towards Sustainability**: *Understanding transformation processes and options, assessing how these relate to human values, emerging technologies and economic development pathways, and evaluating strategies for governing and managing the global environment across sectors and scales*

The proposed theme on Transformation towards Sustainability will go beyond assessing and implementing current responses to global change, to consider the more fundamental, innovative and long-term transformations that are needed to move towards a sustainable future. There are major knowledge gaps in this area and in particular, on how such transformations can be achieved. Future Earth will develop knowledge to understand, implement and evaluate these transformations which might include significant shifts in political, economic and cultural values, changes in institutional structures and individual behaviours, large-scale systems changes and technological innovations that reduce the rate, scale and magnitude of global environmental change and its consequences.

In selecting this major research theme Future Earth signals the need and willingness of the global environmental change research community to take on the challenges of innovation, global governance and alternative solutions that will bring society and the earth system towards more sustainable futures. This theme is intended to engage social and natural scientists, economist, engineers, the humanities and other disciplines in creative approaches to our future and in finding new forms of international and interdisciplinary collaboration.

The GEC research community has a number of past and ongoing projects that have addressed issues of transformation and governance for a sustainable earth system. For example, the Industrial Transformation (IT) project studied interactions between technology, society and industry as they related to the causes of environmental change and alternative solutions. The Institutional Dimensions of Global Environmental Change (IDGEC) sought insights into the multiscale governance of the environment with work continuing within the Earth System Governance (ESG) project to explore political solutions and novel, more effective governance systems to cope with the current transitions in the biogeochemical systems of our planet. These projects show how responding to global environmental change is not just a matter for national governments but also for local governments and international organizations, civil society, the private sector, and individuals.

Understanding the many feedbacks from human responses and governance to Earth system processes requires close collaboration between natural and social scientists, economists and engineers in, for example, projecting the impacts of energy policy or ecosystem management on biogeochemical cycles and biodiversity or understanding how policy and international agreements shape demands on science for on-going monitoring of greenhouse gas emissions or species. Assessing the costs or benefits of different management and governance choices is another important arena for international collaboration and also an important opportunity to partner with the private sector. Another research challenge is to connect trends and policies in engineering, technology and business to their impacts on efforts to foster more sustainable individual and institutional behaviours through innovation and consumption choices. Finally, identifying the social and cultural consequences of different response strategies, including real or perceived winners and losers and how these change over time, is an important area for research.

Research projects under this theme might examine the ethical implications and technical challenges of new economic models, species relocation or climate- and geoengineering and processes of deliberative decision-making, participation, economic valuation and business

management. Insights into past transformations, such as mass extinctions or the industrial and green revolution and how and why notions of the successful, good, ethical and sustainable life have developed over time and across cultures are also relevant research areas (e.g. PAGES, IHOPE, IT). Research into innovation pathways, from institutional and engineering designs to strategies for stimulating growth of new ideas in support of global sustainability, will also be central to this theme.

Under this theme Future Earth can investigate the effectiveness and risks of new technologies that are designed to provide solutions to global sustainability, such as geoengineering, new energy sources, and synthetic biology. It aims to engage with researchers who are rethinking economic systems and indicators in the context of sustainability, who are contributing to new thinking on politics and approaches to democracy, and who are exploring the links between social practices and human behaviour. Research on the communication of change and the development of new narratives and cultural stories can contribute to improved understandings of transformation. Pathways to transformation can benefit also from scenario and visioning exercises that provide understandings of alternative futures, as well as the trade-offs and co-benefits involved in different choices.

The Transition Team discussed several areas where research into transformation for sustainability is particularly timely and urgent. The first is the challenge of *transition to a low carbon society*. There is clear scientific evidence that current patterns of energy and resource use are producing greenhouse gas emissions that are clearly linked to risks of climate change (e.g. GCP), and scientists have already been asked to analyse the pathways for a global transition to low carbon societies across the world (e.g. IT, EMF, IEA). This implies a major economic and technological transition, with profound implications in areas such as engineering, transportation, business models and behaviour. It is likely to require large shifts in sectors ranging from agriculture and forestry to energy utilities and large consumer-based industries. Climate science and energy analysts face major research challenges to provide more robust scenarios for understanding the implications of energy and land use choices for biogeochemistry, carbon and climate. Future Earth has the opportunity to provide even more integrated approaches to energy and climate assessments such as IPCC, through research on the interactions between energy, land and climate systems, the implications of policy choices for greenhouse gas emissions, and the co-benefits and trade offs between different energy and land use options and between climate change mitigation and adaptation (CMIP). Technical innovation alone will not be a sufficient pathway to low carbon societies; such a goal may require changes in energy systems, economic systems, social practices, behaviour, and consumption. The transition to a low carbon society must also confront the need for more safe

and affordable energy to meet increasing demands, particularly in developing parts of the world that currently lack access to electricity.

A second key transition is associated with the sustainable use of the ocean and the possibilities for *sustainable 'blue' societies* who live from and along the seas. Most of the ocean area is a global commons, owned by no nation and weakly managed through international cooperation. The oceans are a source of essential living and non-living resources; coastal regions are home to the majority of the world's population and the open seas are key to global trade and security. In particular, the coastal systems provide fish-based foods and livelihoods for a significant proportion of the world's population. Global change research is showing that oceans are increasingly affected by human actions, including anthropogenic $CO_2$ emissions, acidification, non-sustainable fisheries, large-scale waste disposal and other forms of pollution but there are many critical knowledge gaps in observations, models, and the human use of the oceans that limit opportunities to balance ocean use and protection. There is rapid growth in innovative "blue technologies," technologies that will either be used in, or drawn from, the seas and oceans and should have the potential to significantly contribute to society and/or to marine science itself. There are also proposals for 'blue societies' that live in greater harmony with oceans and to include new protections for marine ecosystems within international treaties. There are several on-going international projects (e.g. the Belmont Forum/G8HORCS Coastal Zones Vulnerability Collaborative Research Action, LOICZ, UNESCO-IOC, CLIVAR, IMBER, SOLAS) that focus on oceans and coasts, including interactions between marine biogeochemistry and ecosystems; land, ocean and atmospheric interactions; social and economic vulnerability; megacities in coastal regions; marine hazards, fisheries, coral reefs and ocean carbon; and major efforts in ocean monitoring and information sharing. Future Earth could advance integrated research on global change and the oceans by bringing together and enhancing on-going projects to consider how to achieve transformations that support ocean sustainability, inspired by the recognition of humanity's increasing dependency on the oceans and capacity to alter them. Research can help understand how people value the oceans, what this may mean for sustainable interventions to protect them and what sorts of interventions might be successfully introduced.

Other research priorities to support transformations to sustainability include the development of new approaches to economics that include broader measures of sustainability and wealth and research that analyses proposals for a 'green economy'. Another set of research challenges is that of designing cities and infrastructure that both reduce the risks of global environmental change while adapting to the changes that cannot be avoided. How can cities, food, water and energy systems be designed to adapt to temperatures that could exceed 4 degrees C? The

explosion of new forms of communication, networking and amount of information associated with computing, the Internet and new media is one of the biggest contemporary transformations. How this wealth of information and new options for collaboration can be harnessed in seeking pathways to sustainability requires new research. For example, understanding how to analyse and share this mass of data and information to improve our understanding of society, to provide observations of environmental change, and to identify and scale up solutions is critical to transformation processes.

What types of research questions and projects can contribute to the Global Development research theme? The Future Earth Transition Team identified the following example research questions to illustrate potential research priorities that can be addressed by current, updated or new collaborative international efforts:

- How can governance and decision-making be aligned across different levels, issues, and places to manage global environmental change and promote sustainable development? What is known about the successes and failures of different actors in managing global environmental change, such as government, business, or international organizations, at different scales, and using different strategies, such as regulation, certification, standards, or taxes in managing global environmental change?
- Can emerging technologies provide viable solutions to global environmental change and promote sustainable development? How can technology and infrastructure choices be combined with changes in institutions and behaviors to achieve low carbon transitions, food security and safe water?
- How do values, beliefs and worldviews influence individual and collective behavior to more sustainable lifestyles, patterns of trade, production and consumption? What triggers and facilitates deliberate transformations at the individual, organizational, and systems levels; what socio-political and ecological risks does it entail?
- What do we know about past transformations of the Earth system, as well as in ideas, technology and economy and how can the knowledge and lessons learned guide future choices?
- What are the longer-term pathways towards sustainable urban futures and landscapes, successful and sustainable 'blue societies, and a green economy?
- How can the earth and social system adapt to environmental changes that could include warming of more than 4C over the next century?
- Can our present economic systems, ideas and development practices provide the necessary framework to achieve global sustainability and if not, what can be done to

revise, redesign and/or innovate economic systems, measures, goals and development policies for global sustainability?

- What are the implications of efforts to govern and manage the earth system for sustainability for scientific observations, monitoring, indicators and analysis? What science is needed to evaluate and assess policies and facilitate and legitimate transformation? How can the massive volume of new geophysical and social data, including local knowledge and social media be managed and analysed so as to provide new insights into the causes, nature and consequences of global environmental change and to facilitate the identification and diffusion of solutions?

The Transformations towards Sustainability research theme will require partnerships that engage a wide range of stakeholders who are working on sustainable futures, including communities, businesses, humanitarian and conservation groups, spiritual and cultural leaders, and citizens who are re-evaluating their lifestyles and legacies for their descendants. An exciting research agenda could be developed in collaboration with the most innovative, creative and solutions oriented thinkers from science, companies, and civil society. For example, such a group would think about innovation in infrastructure, design and planning because much of what is being built and designed today has a long life time and will frame future economies, settlements and environmental impacts. Or a group of spiritual and cultural leaders might work with scholars from the social sciences, arts and humanities to consider how to communicate values that inspire positive and fair solutions for society and sustainability.

***Crosscutting Capabilities***

The ICSU-ISSC Visioning project and the Belmont challenge identified several core capabilities needed to respond to the grand challenges of global environmental change including modeling and observations. The Future Earth Transition Team has identified additional cross cutting capabilities needed to advance the science of global environmental change and translate it into useful knowledge for decision making and sustainable development. Many of these capabilities lie beyond the boundaries of the Future Earth initiative, residing in national and international observing systems, modeling centers, training programs, and disciplines.

The proposed integrated research themes for Future Earth critically depend on access to these capabilities such as observing networks, high performance computing, Earth system models, theoretical frameworks, data management systems and research infrastructures and appropriate arrangements need to be made to enable access. Future Earth science might place new demands on existing systems or might contribute insights and ideas about how existing platforms could be enhanced or all together new systems be established. Cross cutting

capabilities may provide fruitful opportunities for workshops and collaborative research plans and for bringing and training new groups of researchers into international global change research.

| | ***Proposed Cross Cutting Capabilities*** |
|---|---|
| C1 | **Observing Systems** |
| C2 | **Data Systems** |
| C3 | **Earth System Modeling** |
| C4 | **Theory Development** |
| C5 | **Synthesis and Assessments** |
| C6 | **Capacity Development and Education** |
| C7 | **Communication** |
| C8 | **Science-Policy Interface and interactions** |

**Table 2.** Proposed cross-cutting capabilities for Future Earth.

As shown in Table 2, proposed crosscutting capabilities, that might be advanced through collaborations and workshops, include:

**Observing Systems**: Future Earth research requires access to a sustained capability to observe changes across the Earth system, to discover unknown relationships, and to drive Earth system models. This recognizes that many key scientific and societal questions concerning global sustainability relate to natural variability and environmental change and to changes in socioeconomic conditions and resource use. The demands for observations are growing in volume and diversity, so new observing and data management technologies are needed to provide the necessary time and space coverage, and manage the resulting datasets to maximize their use. Future Earth will critically depend on major international systems including GEOSS, GCOS and GOOS which aim to respond to these observing needs, as well as the systematic observations of international and national agencies such as FAO on food, forests and agriculture and WHO on health, but must also support the emergence of international networks in areas where observing systems are at an earlier stage of development, for example, biodiversity or human activities.

**Data Systems**. Future Earth will need access and will bring large volumes of diverse environmental or social data together. As observing, surveying and modeling systems become more complex, the challenge of accessing and bringing large volumes of diverse environmental or social data together increases. Future Earth will depend on important international initiatives, such as the ICSU World Data System, which aim to ensure that data holdings are easily discoverable and accessible, seamlessly across the range of environmental disciplines and data types. It will be essential that data be accompanied by: meta-data that characterize the data, including information on data quality; and, tools to access, manipulate and visualize the data. There is a need to prioritize the development of assimilation schemes to synthesize different data types and to confront observational data with output from numerical models.

**Earth System Modeling**: Future Earth will depend on access to state of the art Earth system and integrated assessment models and will contribute to a next generation of models that better capture the dynamics of human-environment interactions, feedbacks and thresholds in the Earth system and that allow for predictions of risks and change on longer time and more detailed regional scales, and take advantage of computing power and skills from a broader range of countries. Understanding of the Earth system is maturing to the extent that the development of useful Earth system models is feasible (e.g. CLIVAR, GEWEX, SPARC, IGAC). However challenges remain in: filling knowledge gaps of environmental and social processes even in well understood sectors (e.g. atmospheric convection or international trade); representing the biosphere or decision-making, where process descriptions remain at an early stage of understanding; representing coupled systems and interfaces where physical and biological processes often occur most rapidly; and finding the most computationally efficient and flexible way to couple models of the components of the Earth system.

**Theory Development**: Future Earth will need to engage with theoretical debates, drawing from a wide range of disciplines, on how natural systems function and on the fundamental explanations of social, economic and political behaviour and institutions, to the extent that these debates influence approaches to research, provide insights and solutions and encourage or prevent collaboration across disciplines. Our understanding of Earth and societal systems is underpinned by basic theories of how natural and social systems function and often differing views on the fundamental explanations of social, economic and political behaviour and institutions. These theories draw on a wide range of disciplines, from physics and chemistry to anthropology, economics or philosophy and new ideas from these fields often have significant impact on explanations of global environmental change. For example, explanations of human response to environmental change can vary with different theoretical perspectives from the social sciences that assume that people make free rational choices on economic grounds or are more influenced by discourse, culture or control by powerful interests. In ecology, differing

theories about basic ecosystem functions can produce different models of how biodiversity may be affected by global environmental change. While theoretical developments from natural and social sciences as well as the humanities will enter into many of the research themes, crosscutting workshops on topics such social or ecological theory may be helpful to the themes and to entraining a broader group of researchers to work on global environmental change.

In addition to these crosscutting research capabilities Future Earth will prioritize:

**Synthesis and Assessments**: Global environmental change research has already made major contributions to assessments that have been used in policy making and education such as the IPCC, MEA and the UNEP GEO. In general such synthesis efforts and assessments that draw on expertise from many countries provide an important and legitimate basis for decision-making. Future Earth projects will be asked to consider how their results will contribute to key assessments at national and international levels and to respond to the research gaps and agendas that have been identified in assessments

**Capacity Development and Education**: Future Earth projects will involve capacity building that will train researchers in new techniques, involve early career scientists and students, and support stakeholders in developing their abilities and contributing to the training of researchers. Several existing initiatives, such as START, the UNU education programs, or a wide range of existing young scientist workshops include cross-cutting training and capacity building efforts and Future Earth projects can learn from and expand on these activities. Some existing projects also include a substantial educational component, developing outreach materials and curricula for formal and informal education including university courses, teacher training, museums and public communication.

**Communication:** The communication and education strategy for Future Earth is addressed elsewhere in the transition team report but research and evaluation of communication and education in the area of global environmental change is an important cross cutting activity for the international research community. This research covers research into the role of the media, educational institutions and advertising in shaping public views on environment and into how to use both formal research and local knowledge as information for adaptive management of environmental problems (e.g. KLSC). This brings new areas of expertise from psychology, communication, extension, and education research to the challenges of global change.

**Science-Policy Interface and Interaction**: Future Earth intends to co-design and, where appropriate, implement research with the users of that research and connect research to decision making, promoting the evolution and delivery of collaborative research agendas and knowledge that emerge from sustained engagement. Future Earth approaches issues of

research use as both a research theme and an outreach function. Although there is a body of research on knowledge transfer and decision support it is not well organized at the international level, with many gaps in understanding the basis and barriers in different regions and a need for innovation. Efforts to transfer knowledge to users include proposals for environmental information services (such as the GFCS), global assessments such as IPCC and IPBES, investment in web and social media, press releases and educational curricula. Future Earth encourages an approach that avoids one-way delivery of science to users but promotes the evolution and delivery of collaborative research agendas and knowledge that emerge from sustained engagement. This engagement can be guided by research into the science-policy or science-user interface, by work in decision sciences and by rigourous and sustained evaluation of science-policy activities and information exchange.

**Annex 1**

**Future Earth design and delivery principles**

Future Earth will be guided by the overarching strategic research framework set out in this document and its research will operate in an inclusive, integrative and solution-oriented way, emphasizing the following key principles:

- *Scientific excellence:* An overarching element to these key principles is Future Earth's commitment to support science of the highest quality.
- *International scope*: Future Earth is does not encompass all environment and development research but focuses on areas where international research co-ordination is needed for successful analysis and solutions.
- *Integration*: Future Earth should draw on expertise in natural and social science, as well as engineering, the humanities and professions such as planning and law. This must be complemented by strong disciplinary excellence that contributes insights to integrated projects, with a focus on the intersection of global environmental change and sustainable development.
- *Co-design* and co-production: the research agenda and programmes should be co-designed and co-produced by researchers in collaboration working with various stakeholders– in governments, industry and business, and civil society.
- '*Bottom*-up' *inspiration*: the Future Earth approach will emphasize the importance of 'bottom-up' ideas from the research community in designing the projects that respond to challenges.
- *Solution-oriented*: by providing foresight of changes and risks, testing the effectiveness of responses and providing a knowledge base for new innovations
- *Inclusive*: Future Earth intends to include existing international Global Environmental Change (GEC) core projects and related national activities, as well as other existing international and national GEC research activities in a framework that strengthens existing projects and provides them with new opportunities. Strong attention will be given to regional engagement, geographic and gender balance, capacity building and networking.

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