Chapter 1

Earth system science and society: a focus on the anthroposphere

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In this chapter, we explore the challenges that Earth system researchers face in addressing human-induced global environmental changes and the societal consequences of global change within their research toolkit. We focus on areas of research that have particular resonance with today's social and political demands.

1.1 The Earth system and the 'problematic human'[1]

1.1.1 The state of play and our position

The great scientific challenge faced by today's global change scientists is to understand the Earth system. Part of this is knowing that we ourselves, as human beings, are an influential component of that system and that the understanding we develop shapes our responses to the environmental changes we see around us. In scientific terms, most of the fundamental workings of our planet, including the processes that change climate and landscapes on short and long timescales, were already well understood by the end of the twentieth century. Earth system science is the field of study that has brought these areas of knowledge together. It has not just provided insight into the phenomena of global environmental change, but also explained the 'hows' and 'whys' behind them, bringing insights into the future prospects for our planet. The enormity of the challenge lies in the realization that we are seeking to understand and predict the properties of a complex adaptive system of which we are a part, recognizing that our choices and our agency as human beings are important controls on its workings. More than that, our ability to deploy our knowledge and make choices about our actions is an important facet, perhaps even a characterizing trait, of our existence.

For scientists in all the contributing fields of inquiry, this development marks a shift from the pursuit of knowledge largely for its own sake to robust predictive knowledge that is required – urgently, many argue – for application in the real world. The prediction of any system where humans play a part has long challenged both scientists and philosophers. Without venturing into those debates here, the prediction of socio-environmental systems nevertheless presents us with a very practical conundrum: our current understanding, even the knowledge codified in the most sophisticated models, is a partial and simplified picture of reality. Our predictions based on this understanding may be wrong and the unintended consequences of action based on those predictions may be severe. However, not to use the available understanding would be to take a perverse and unhelpful position.

In this chapter, we often take the historic view, looking at past scientific efforts in global change research, particularly those efforts framed in terms of global systems. Quantitative models of human dynamics, such as Thomas Malthus' eighteenth-century calculations of Earth's carrying capacity for human population, and the Club of Rome's efforts in the 1970s to measure the limits to socio-economic growth, have generally done a poor job. Nevertheless, it is important to learn from these efforts. One reason they failed is that they did not

[1] With thanks to Lesley Head, University of Wollongong, for this expression. See Head, L. (2007) Cultural ecology: the problematic human and the terms of engagement, *Progress in Human Geography*, **31**, 837.

Understanding the Earth System: Global Change Science for Application, eds. Sarah E. Cornell, I. Colin Prentice, Joanna I. House and Catherine J. Downy. Published by Cambridge University Press © Cambridge University Press 2012.

adequately take into account human agency. In short, we have continually underestimated the role of the social and economic context when we have tried to model the impact of global change. Even where features of socio-economic change evident at the global level allow for a measure of scientific generalization to be made, they are often not included nor examined in models. For example, below we mention the widely observed demographic transition in human population growth: this is just as good and precise a 'law of nature' as most in biology. At the opposite end of the spectrum, there are models of the Earth system that omit human activity altogether. Contemporary physical climate models work as effectively (which is to say, very effectively indeed in describing climate dynamics) for all planets with an atmosphere, ocean and land surface. They reach the limits of their predictive power when they need to bring people into the equation. One challenge we face is that the climate modelling enterprise has defined contemporary climate change in strictly physical terms, i.e. as a physical change driven by increasing amounts of greenhouse gases in the atmosphere. However, from a socio-environmental perspective, there are many ways of looking at and defining climate change. There is a risk that using one dominant way of looking at the problem can drive the policy agenda to the exclusion of other important approaches for finding practically useful solutions. Predictive power alone is not synonymous with usefulness.

What do we require from Earth system science, defined broadly as the science of both the climate system and the human dimension (or the 'anthroposphere')? Ideally, we would like to develop a science that addresses both the human and the natural-environmental components of the system, and that can tell us something about how this complex, coupled socio-ecological system works (Young *et al.*, 2006). Modelling is an essential part of this process. Much of the remainder of this book tries to describe the present state of the models (conceptual and numerical) that underpin both the science and the political decision-making process relating to global environmental change. Earth system science should also be informed by an effective understanding of how society steers itself, so that the scientific process can be more transparent and more responsive to the needs of society. In the context of the unprecedented magnitude and rate of global environmental changes, many people consider that major social, political and economic changes are needed to cope with, manage or avert the worst impacts. These changes should involve new structures and dialogues between scientists and other members of society, for participation in collective decision-making about the future.

1.1.2 The human dimensions of global environmental change: controls, consequences and context

The rapidly expanding science of Earth's climate, biogeochemical processes, and their interconnections is complex, yet it needs to be understood much more widely if society is to respond to current environmental pressures and projected future changes in an informed way. Although our main focus in this book is on summarizing and explaining the biophysical science of global change, a deep understanding of the Earth system will also include insights from the study of human behaviour.

First of all, human activities, more than ever before, are important ***controls*** on Earth's biophysical processes.

The trajectory of human population, especially since the Industrial Revolution, has been one of steady and rapid growth. In the early nineteenth century, the political economist Thomas Malthus famously argued that unconstrained population growth would naturally follow a 'geometric ratio', or exponential growth, while the supply of life-sustaining resources would not. The result would be an overshoot of the human population and a catastrophic check (famine, disease, conflict) on human numbers. Although Malthus was plausibly describing the trends he observed, by simply extending them into the future, his predictions were very wrong. Earth's population has shown some periods of exponential growth – for instance, doubling from 1.5 billion to 3 billion inhabitants between about 1880 and 1960 (80 years), and then again to 6 billion between 1960 and 2000 (40 years). But it is unlikely that the Earth's human population will double again, so both the unfolding of history and a more sophisticated understanding of the dynamics of population have now removed the spectre of catastrophic overpopulation (Cohen, 1998). In 2011, world population reached 7 billion inhabitants (United Nations, 2011), and current estimates suggest that our numbers will peak at approximately 9 billion sometime over the next century (Lutz *et al.*, 2008; United Nations, 2011). Malthus was wrong because he failed to predict the 'demographic transition', a widely observed phenomenon where birth *and* death rates both fall as economic development progresses (e.g. Chesnais, 1992), halting the exponential pattern of growth. Rates of growth of global population have declined in the last two or three decades (US Census Bureau, 2011). Malthus also failed to predict the Haber–Bosch process for nitrogenous fertilizer production and the hybridization of seeds (along with other technological innovations and transformations in agricultural systems), which have made it possible for the world to produce enough food for today's population. Today, the problem of hunger is primarily one of economics and politics affecting food supplies, not one of Earth's capacity for food production. So, while some argue that the world will need to produce considerably more food by mid-century (Bruinsma, 2009), others point out that using the food we currently have more efficiently should be enough to continue feeding the world (Smil, 2001).

Steffen *et al.* (2004) reviewed the impacts on Earth of this rapid population growth, finding similar rapid rises in natural resource use (Figure 1.1), bringing unintended consequences for ecosystems such as rising levels of air and water pollution and environmental degradation. However, the impact of human activity on the natural environment is far from being a simple linear function of population. The widely quoted 'IPAT equation' (Ehrlich and Holdren, 1971; Commoner, 1972; Box 1.1) frames the environmental impact of human activities as a function of technological change and economic growth as well as population: impact = *f*(population × affluence × technology). It highlights the fact that society's increasing technological capability (the *T* in the equation) means people can access more of Earth's natural resources and transform them for their use more effectively, and also that increased affluence (*A*) enables individuals in the population to use and consume more resources. The analysis conducted by Steffen *et al.* (2004) shows how affluence and technology are often much more influential on impact than population numbers.

Box 1.1 The IPAT equation

A simple formulation that has widely been used in Earth system science describes the *impact* of human activity on the natural environment as a function of *population*, *affluence* and *technology*. The interactions of these three terms have been explored empirically in a range of socio-environmental contexts, including resource consumption, food security and energy-systems analysis.

$$\text{Impact} = f(\text{Population, Affluence, Technology})$$

The relationship between impact and the PAT terms is not simple (Chertow, 2001). The original equation was simply multiplicative ($I = P \times A \times T$). This is a useful heuristic for linking impact and socio-economic development, and many nations in the world have shown increasing impacts as they developed in the past, but it is not a predictive law. Empirical studies show strongly non-linear relationships between the terms (Dietz and Rosa, 1997; Dietz *et al.*, 2007). Recent studies (e.g. Pitcher, 2009; Davis and Caldeira, 2010) highlight the fact that consumption levels (the *A* and *T* dimensions) are the 'thermostats' on impact, not population itself, warning against the errors of simple Malthusianism and using the formulation in 'green-revolution' arguments for technological innovation to reduce impact.

A close relative of the IPAT equation, the Kaya Identity (Kaya and Yokobori, 1993) has been developed in the context of energy and greenhouse-gas emissions. It has been applied in IPCC emission studies and scenario development (IPCC, 2001).

$$CO_2 \text{ emissions} = \text{Population} \times \underset{\text{(goods consumed per capita)}}{\text{Consumption intensity}} \times \underset{\text{(energy input per unit goods)}}{\text{Energy intensity}} \times \underset{(CO_2 \text{ output per unit energy})}{\text{Carbon intensity}}$$

These formulations show that multi-pronged responses to environmental impact can – and should – be explored. Thus, for climate change, responses could include societal learning and change, economic incentives and instruments, improved efficiency, energy substitution, CO_2 sequestration.

The impact of the human endeavour is now manifest at the global scale (Figure 1.2). Only the most hostile environments – deserts, ice-covered lands and seas, and some of the densest areas of forest remote from population centres – can still be regarded as near-pristine. The rates of human-induced changes to land, marine and atmospheric environments and the fact that they have become discernible at the global scale, have prompted a proposal for the adoption of the term 'Anthropocene' as a geological period. This is not merely a light-hearted neologism to describe contemporary environmental change: stratigraphers are engaging in international discussions about the merit and feasibility of defining a period of human perturbation of the global environment, and designating the Anthropocene as a formal unit of geological time (Zalasiewicz *et al.*, 2010).

The second important reason that Earth system science needs to give attention to knowledge from

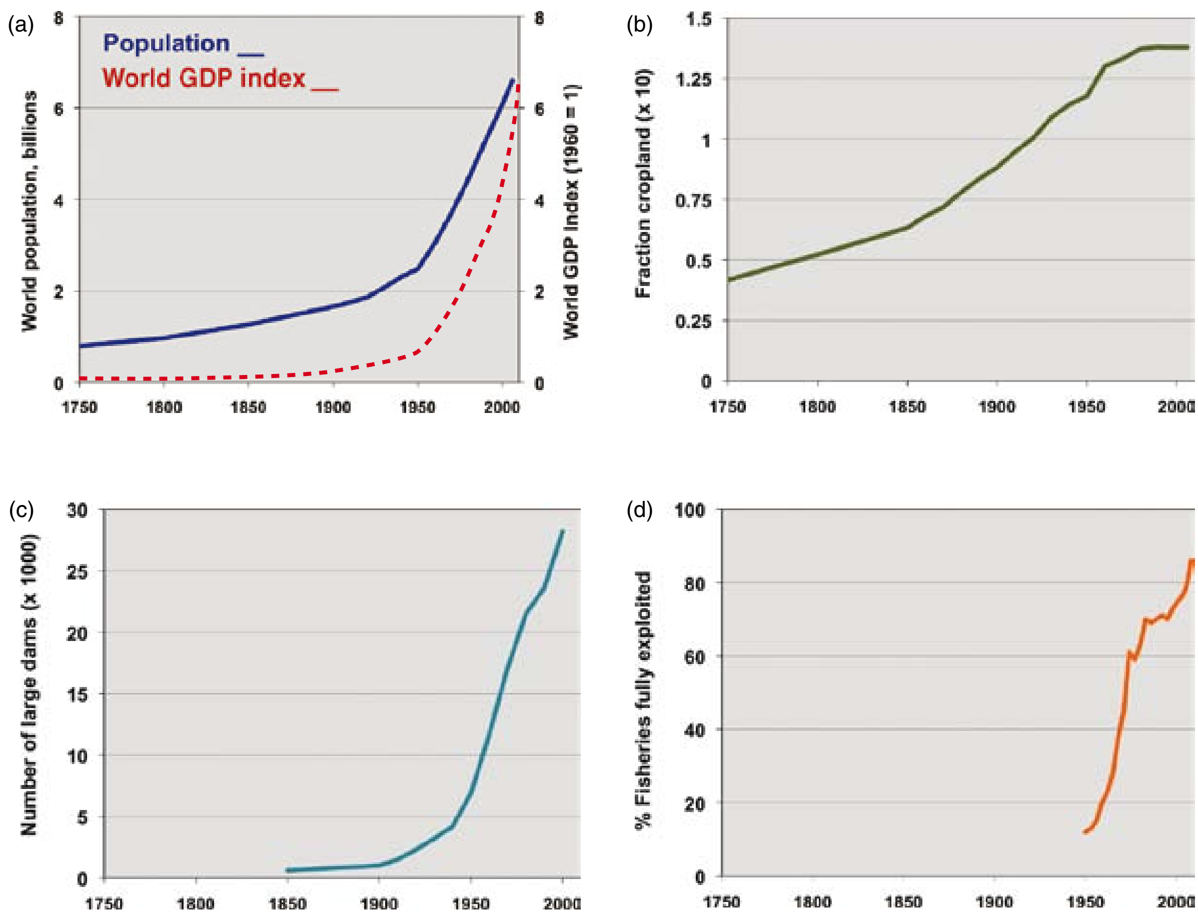

Figure 1.1 Some global socio-environmental trends since industrialization.

(a) World human population (US Bureau of the Census International Database, www.census.gov/ipc/www/worldpop.html; solid line) and the aggregate world gross domestic product indexed against 1960 world GDP (dashed line; data up to 2005 from the Earth Policy Institute, www.earth-policy.org/indicators/C53; updated to 2010 with data from the International Monetary Fund World Economic Outlook, www.imf.org/external/pubs/ft/weo).
(b) Global land use as cropland (Ramankutty and Foley, 1999; fraction of total land area multiplied by 10 for convenient scaling).
(c) Number of dams larger than 15 m on the world's rivers (data from World Commission on Dams (2000), including estimates for 2000 shown in the annex of that report).
(d) Percentage of global fisheries that are fully exploited, overfished or depleted (data from 1974 to present from FAO (2010); earlier data from FAOSTAT (2002) statistical databases, cited in Steffen *et al.*, 2004).

the social sciences is that humans experience the ***consequences*** of global environmental change.

The fact that the natural environment presents hazards to people is nothing new. Newspapers are full of reports of humanitarian disasters caused by droughts, floods, storms and other geological and climatic events. Similarly, it is widely recognized that human society has the capability to create serious environmental risks for itself. Communities, societies and, arguably, entire empires, have done so in the past with catastrophic consequences (Ponting, 2007). In this context, Earth system science provides powerful concepts and tools that can be used in assessing and predicting the risks to people and society of climate change and other global environmental changes, and in informing responses to these potential changes. Understanding human vulnerability in the context of these changes is as essential as understanding their biophysical dynamics.

Bringing a systems perspective to bear on these issues also allows the interplay of causes and consequences to be addressed. An iconic example of human-caused environmental disaster, often used as a warning metaphor for society's current unsustainable

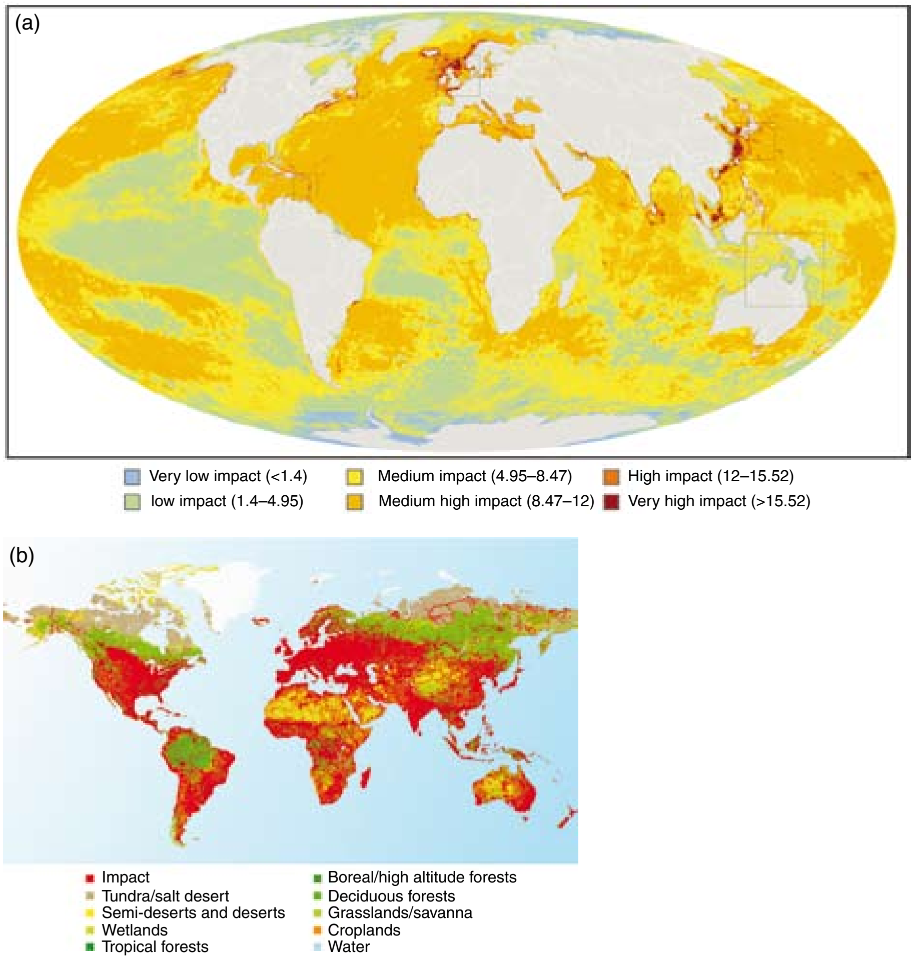

Figure 1.2 The scale of global anthropogenic impact.

(a) Human perturbation of marine ecosystems This map was constructed by overlaying 17 global data sets of drivers of ecosystem change, such as fishing activity, shipping, and riverine and long-range pollution. Reproduced with permission from Halpern *et al.*, 2008.

(b) Human impact on the land environment, modelled using GLOBIO-2 (image by Hugo Ahlenius, UNEP/GRID-Arendal, 2002; reproduced with permission). The GLOBIO model (www.globio.info) makes spatial assessments of the consequences for land biodiversity of human drivers like land use, pollution and infrastructure.

situation, is the total deforestation of Easter Island in the eighteenth and nineteenth centuries, and the linked socio-political turbulence. It is also an example of the need to take a deeper and more critical look at the human dimensions of change: the balance of social science research (summarized in Rainbird, 2002) indicates that, apart from tree-felling, other, yet very familiar, human factors played a major role in the degeneration of Easter Island's society and environment. Population collapsed, and social structures with them, following contact with European explorers who introduced new diseases and destructive animals, and raided repeatedly for slaves. In Section 1.3 below, we summarize areas of social science research that are actively exploring global environmental change issues. These fields of research enable a fuller perspective to be taken, necessary to prevent over-simplification or the proliferation of modern myths of environmental threats.

The third reason for explicitly addressing human society and its activities within the field of Earth system science is that society is the *context* in which Earth system research actually happens, and where the knowledge produced is directed towards practical action. The knowledge that scientists produce will go into the public and policy domains, where it faces many possible fates: this knowledge can be debated, reconfigured and developed in the context of other fields of knowledge, and naturally it can be used in decision-making processes. Earth system science is now deeply embedded in the processes and institutions that inform society's planning for climate change adaptation and mitigation, and for many other policy responses to global environmental change. This situation represents a marked shift in the way that science is done and, in our view, it brings new responsibilities and challenges along with new academic insights into our Earth.

Cambridge University Press
978-1-107-00936-3 - Understanding the Earth System: Global Change Science for Application
Edited by Sarah E. Cornell, I. Colin Prentice, Joanna I. House and Catherine J. Downy
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1.2 Conceptualizing the 'human dimension' from an Earth system perspective

Given the importance of people in causing and being affected by global environmental change, the research community interested in these issues faces a serious challenge: how to conceptualize and embed human agency and socio-economic context in our understanding of the Earth system.

This challenge is highlighted by a debate that has been simmering between scholars for at least 350 years. To a very large extent, a primary activity in post-Enlightenment science has been *analysis* – the breaking up of the complex world into comprehensible pieces for in-depth investigation. Established by the likes of René Descartes, whose famous maxim *Cogito ergo sum* reflected an attempt to explain the human experience rationally, by reducing it to fundamental truths, analysis through reductionism has been the basis for many (if not most) of our scientific discoveries in the modern era. This point is highlighted by futurist and social commentator Alvin Toffler (1984) who wrote,

> One of the most highly developed skills in contemporary Western civilization is dissection: the split-up of problems into their smallest possible components. We are good at it. So good, we often forget to put the pieces back together again.

Without denying the immense value of reductionist research in both the biophysical and human domains, Toffler, and many others since, have argued that to address the global challenges that face us today, the balance needs to shift back towards *synthesis*: bringing our collective perspective back up to the better-rendered 'big picture' of our world. This world is a complex world, and it is inescapable that improving understanding requires the integration of multiple perspectives. If Earth system science is to be a part of this integration process, it requires a much fuller recognition of the interconnectivity of its social and environmental components.

There have been many calls for more such integrated knowledge from environmental research funders, government bodies and the research community itself (Box 1.2), in response to the challenges posed by global social and environmental changes. The International Human Dimensions Programme on Global Environmental Change came into existence in the mid 1990s, sponsored by both the International Council of Science Unions (ICSU) and the International Social Sciences Council (ISSC), to foster social-science research on global environmental change and to support collaborative research efforts across the social and natural sciences. In 2001, the four international global change research programmes jointly issued the Amsterdam Declaration on Global Change, which included a description of how this more integrative research should develop:

> The scientific communities of [the] international global change research programmes … recognise that, in addition to the threat of significant climate change, there is growing concern over the ever-increasing human modification of other aspects of the global environment and the consequent implications for human wellbeing. A new system of global environmental science is required. This is beginning to evolve from complementary approaches of the international global change research programmes and needs strengthening and further development. It will draw strongly on the existing and expanding disciplinary base of global change science; integrate across disciplines, environment and development issues and the natural and social sciences; collaborate across national boundaries on the basis of shared and secure infrastructure; intensify efforts to enable the full involvement of developing country scientists; and employ the complementary strengths of nations and regions to build an efficient international system of global environmental science'.[2]

Box 1.2 The current research and policy focus on 'understanding the Anthropocene'

Many organizations involved in the research process are currently orienting themselves towards better transdisciplinary integrated knowledge of global change, recognizing the importance of delivering this knowledge in a timely way to decision-makers in society in order to meet the growing sustainability challenge. This emphasis on better interaction between natural and human sciences, and on the urgency of the knowledge need, is evident at all levels – international and intergovernmental, regional and national:

- The United Nations Education, Scientific and Cultural Organisation (UNESCO) launched its Climate Change Initiative in 2009. It supports interdisciplinary integration of knowledge about climate, promoting the use of its biosphere reserves and World Heritage sites for research and implementation of climate risk management policies. A core programme focuses on ensuring

[2] Text in full available on the Earth System Science Partnership website, www.essp.org/index.php?id=41

that environmental ethics, social and human sciences are entrained in responding to climate. Also, UNESCO has designated 2005–2014 as the Decade for Education for Sustainable Development, in which climate change, biodiversity and sustainable lifestyles are key themes. See: www.unesco.org/new/en/natural-sciences/special-themes/global-climate-change and www.unesco.org/new/en/education/themes/leading-the-international-agenda/education-for-sustainable-development/about-us/.

- The ICSU and the ISSC identified a set of 'Grand Challenges' in Earth system science for global sustainability (Reid *et al.*, 2010). They acknowledge the huge advances made in understanding the functioning of the Earth system, but issue a call to action to researchers from the full range of sciences and humanities. The ICSU and the ISSC are also alert to the difficulties of this new mode of working, in terms of institutional structures, research methods and the incentives for participation in this evolving area. See: www.icsu-visioning.org/grand-challenges/
- The Belmont Forum is made up of representatives of funders of global change research from many countries around the world, many of which have supported socio-environmental research since questions of global environmental change first arose in the research agenda. As funders, they are influential in dealing practically with many of the difficulties that ICSU/ISSC identified in their Grand Challenges Visioning initiative. In 2011, the Belmont members made a shared commitment to supporting research that yields knowledge for action to avoid the detrimental impacts of climate change, explicitly requiring interaction of the natural and social sciences. See: www.igfagcr.org/index.php/challenge
- The IPCC itself, as the key organization providing scientific synthesis for decision-makers, has been criticized in the past for having a physical-sciences bias but, since it was formed, its reports have both reflected and shaped moves in the research community towards greater integration in order to better understand the human dimensions of global change. The Fifth Assessment Report currently being prepared puts more emphasis than any previous report on the interplay of socio-economics and biophysical changes, as well as on sustainability and risk management in the adaptation and mitigation responses. See the brochure on www.ipcc.ch/organization/organization_history.shtml
- Recognizing the strategic and practical challenges of integrated research on global change, the four global change programmes (IHDP, IGBP, WCRP and Diversitas) set up the Earth System Science Partnership to provide enabling mechanisms for the science community. It has supported joint projects on cross-cutting issues such as water, carbon, food and human health, as well as regional studies.
- In Europe, the European Commission's Research Advisory Board (EURAB) in 2004 spelled out some necessary improvements to enable Europe's research systems to better meet the transdisciplinary challenges presented by complex environmental systems (European Research Advisory Board, 2004). Its successor, the European Research Area Board envisions a 'New Renaissance', where new ways of thinking will emerge from better linkages between the natural and human sciences. See: http://ec.europa.eu/research/erab/pdf/erab-first-annual-report-06102009_en.pdf.
- The European Science Foundation (ESF) reported on its first Forward Look activity on Earth system science in 2003. That study focused primarily on biophysical changes, informing subsequent research, modelling and observation programmes (including the UK's QUEST programme). In 2009, the ESF launched a second Earth system science Forward Look, this time explicitly concerned with global change and the Anthropocene. This activity, *Responses to Environmental and Societal Challenges for our Unstable Earth*, also grappled less with the science base itself than with the need for new integrative structures and processes in research that are capable of addressing the socio-environmental issues of greatest concern. See: www.esf.org/index.php?id=6198.
- Many national projects and programmes have been developed recently to address the interlinked human and biophysical dimensions of global change. One example in the UK is *Living with Environmental Change* (www.lwec.org.uk), which is a multi-partner initiative involving research councils, government departments and agencies and businesses. *Nordic Strategic Adaptation Research* (www.nord-star.info) links interdisciplinary researchers across the Nordic nations with decision-makers in policy and business, and provides a model (and resources) for similar networks elsewhere in the world. *td-Net* (www.transdisciplinarity.ch) is a network for transdisciplinary research, which shares

information about methods and good practice in this frontier area of study. The *Grupo de Pesquisa em Mudanças Climáticas*, the climate change research group of Brazil's national space research institute INPE (mudancasclimaticas.cptec.inpe.br) is engaged in socio-environmental research involving multiple government, business and academic partners in Brazil and worldwide, but it also seeks to engage directly with journalism forums and organized civil society groups, and it provides a regional focus for other national research and societal engagement efforts across Latin America.

All these groups have recognized the evident need for new kinds of knowledge to equip society better for responding to the many linked challenges of global change. They have set out some institutional and operational principles for working. However, the nature of this newly integrated knowledge is still open to debate. Despite near-universal acknowledgement of the complexity of the Earth system, we still tend to deploy discipline-based approaches to the identification of the research problem. For instance, climate scientists define climate change as a physicochemical problem, the consequence of perturbed atmospheric chemistry, planetary albedo and the like. The Summary for Policy Makers of the IPCC's Fourth Assessment Report (IPCC, 2007) states, '*Causes of Change: Changes in atmospheric concentrations of greenhouse gases and aerosols, land cover and solar radiation alter the energy balance of the climate system.*' In contrast, a leading sociologist, Anthony Giddens, addressed climate change entirely as a political problem in his recent book on the topic (Giddens, 2009); while for economists, it is seen as the '*biggest market failure*' (e.g. van Ierland *et al.*, 2002; Stern, 2007). Of course, climate change is a consequence of all of these things together. The challenge remains in how we understand all of these aspects together, including their interactions.

Various tools have been proposed and tried out. Figure 1.3 shows one of the iconic conceptualizations of the Earth system, known as the Bretherton diagram. It was included in the NASA-sponsored Bretherton Report, '*Earth System Science: A Closer View*' (NASA Advisory Council, 1988), which set out a scientific research agenda for the emerging field of Earth system science. The Bretherton Report was profoundly influential. The development of Earth system models in the period since it was published can be seen as the progressive inclusion of sub-models representing the different boxes and arrows in the diagram, drawing on the findings of many international collaborative research programmes for biogeochemistry and climate science.

The figure shows how scientists viewed the Earth system as a set of interactions between the physical climate system and the biosphere mediated through various global biogeochemical cycles. The dynamics of the system are 'forced' by energy changes associated with natural variations in solar intensity and with the reductions of incoming solar radiation reaching Earth's surface caused by volcanic eruptions shooting ash and sulphate aerosol into the upper layers of the atmosphere. People feature in this diagram as a semi-external forcing on an intricately coupled biogeophysical system. Human activities cause land-use change and are a source of CO_2 and pollutants. These human activities are clearly affected by climate change and dependent on (land) ecosystems.

The Bretherton diagram was an important first step in demonstrating the links between human activity and environmental processes. Overall, however, people were not presented in this approach as being a fully endogenous part of the system. In this framework, the few elements representing all human activity contrast sharply with the more richly resolved processes of the natural world. This asymmetry has been reflected in research investments and international research infrastructure in the area of global environmental change until comparatively recently.

Social research at the global scale emerging at around the same period reflected these growing concerns about societal and environmental change linked to globalization and economic development. The priority research questions articulated in the late 1980s still look very topical today, but they do not fit easily into the Bretherton schema:

> What are the persistent, broad-scale social structures and processes that underlie these changes? In particular, what are the relative roles of the amount and concentration of human population, the character and use of technology, the changing relation between places of production and consumption, and the 'reach' and power of state and other institutional structures? How does the relative importance of these roles for environmental change vary across cultures, and through history? (SSRC, 1988, cited in Clark, 1988)

These questions involve structures, processes, changing dynamics, and causalities – all terms common to systems analysis and familiar to Earth system scientists, but they also address important social concepts, such as power, culture and institutions, that do not

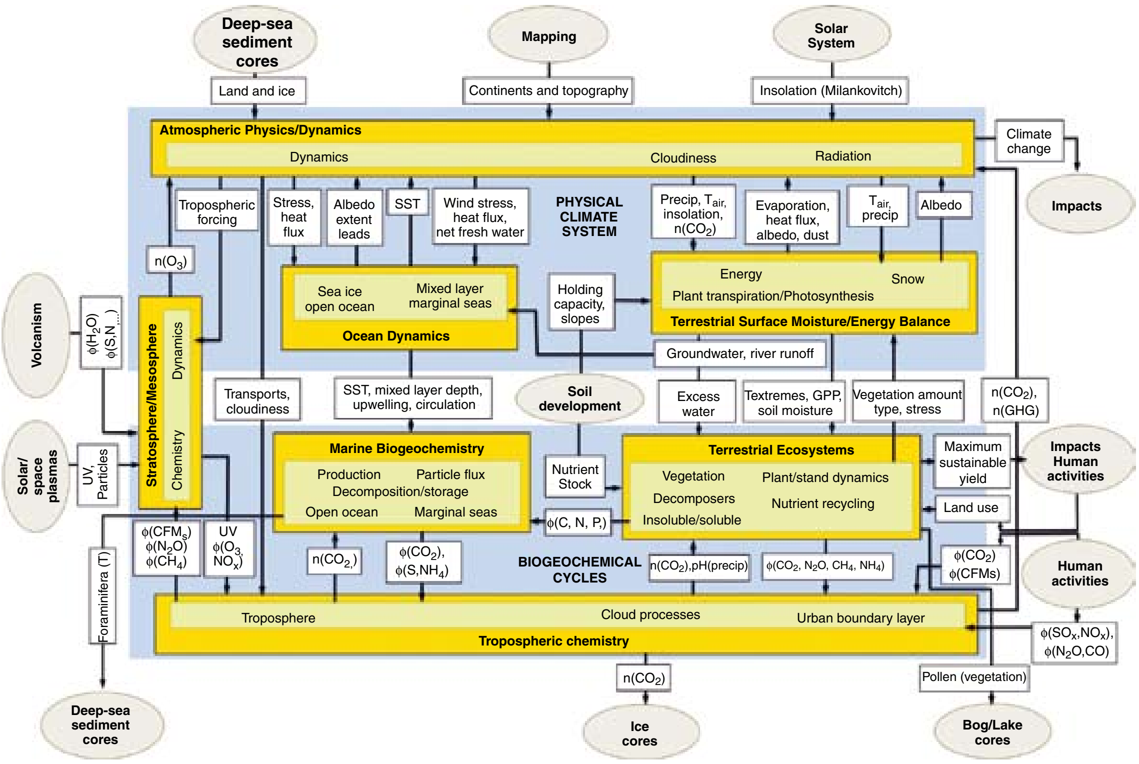

Figure 1.3 The Bretherton diagram (redrawn with permission from NASA; original figure published in *Earth System Science: A Closer View*, Report of the Earth System Science Committee of the NASA Advisory Council (1988), pp. 29–30).
This conceptual model, developed as part of a strategic research plan by the Earth System Science Committee of the NASA Advisory Council, represents Earth system processes occurring at timescales from decades to centuries. The ovals show exchanges with the external environment, or processes that operate over much longer timescales. The arrows connecting the sub-systems represent quantifiable measures that can be included in Earth system models. Contemporary Earth system models now include most of these processes.

translate well into quantitative measurements or computer models. Thus, research exploring these issues developed alongside the biophysical and climate studies, despite the recognition of the inextricable link between human development and the natural environment. Gro Harlem Brundtland, the chair of the World Commission on Environment and Development, wrote in the foreword of *Our Common Future*, the Brundtland Report (1987): 'Environment *is where we all live; and* development *is what we all do in attempting to improve our lot within that abode. The two are inseparable*'. Yet in terms of the research that has informed environmental and development policy, and the framing of the research questions, the social and natural sciences have largely followed separate paths.

Many still regard the complexity and the interdisciplinarity of the research effort now needed as an enormous challenge. The Bretherton diagram is a representation of the Earth system from a physical-sciences perspective. It has been a very important visualization of a set of priority areas for research into environmental and climate processes, but there is a growing discussion in the global change research community of the limitations of thinking of the Earth system in this particular way. Major questions for today's Earth system scientists are how far we have progressed from Bretherton's early conceptualization, and whether and how human activities might be better represented using the next generations of models. '*Structuring support for human dimensions research only around themes defined by natural science is inadequate*' (as stated by the Human Dimensions of Global Environmental Change committee, NRC, 1999; p. 62), but what might a consideration of the key processes and interconnections look like from other perspectives? In particular, what can now be gained in terms of understanding the Earth system if it is viewed from more than just the physical-sciences perspective? This effort must draw on the existing knowledge resources available in a wide range of disciplines, so the focus is increasingly on the 'integration' of knowledge, in ways that accommodate the multiple perspectives and insights from these different fields.

1.2.1 Towards an integrated understanding of the Earth system

The physical-sciences community has been making the most visible and vocal calls for the wider engagement and entrainment of knowledge from other fields, in large part because of the increasing demand for scientific insights to inform policy on climate and global environmental change. The changing interaction between Earth system science and policy is explored more fully later in this chapter; for now, the point is that Earth system science has recognized some important limitations in the deployment of its outputs in the real-world context, with many of these constraints relating to its interface with the human sciences. This recognition is what drives the desire to expand the scope of the field.

However, the methods and approaches of Earth system science are seen by many scholars in other fields as not entirely fit for these purposes, without some kind of transformation. In the view of many social scientists, Earth system science has followed a scientific tradition based on the search for universal laws and principles. In fields with more descriptive and interpretative traditions, there is a concern that the dynamics of the planet and its human inhabitants cannot be adequately described by reductive analysis of the components. Fortunately, many disciplines – and 'interdisciplines' – have well-established approaches to understanding the complex dynamics of a changing world that Earth system science can combine and draw upon.

Another well-debated theme from the social sciences that is beginning to resonate in contemporary Earth system science is their intensely critical concern with how the position of the researcher influences the outcome of the research.

For example, Demeritt (2001) explores the tacit social, cultural and political commitments of climate science, which shape the ways in which particular issues are defined as worthy of research, and determine the methods and techniques for the research inquiry itself. He argues that there is a tendency to '*concentrate upon the uses of scientific knowledge "downstream" in the political process*', and '*discount the ways in which a politics – involving particular cultural understandings, social commitments, and power relations – gets built "upstream" through the technical practices of science itself*' (p. 306). The risks arising from this situation, where embedded assumptions and judgements are not acknowledged, include the messy battles of climate scepticism, opacity in what should be democratic processes of decision-making, and, Demeritt suggests, the problem that people simply are turned off by an overly technical and globally undifferentiated scientific line, precisely when there is a need to engage the global citizenry fully in the societal changes that are needed. The response to public doubts and scientific uncertainty is not merely to provide more and more technical knowledge about the Earth system. There is also a pressing need to recognize, reflect upon and work with the social context of this science, to build the social trust and solidarity that are needed for any effective response to the challenges.

Hulme (2008) explores a different perspective, but also one that is a major concern for social scientists dealing with environmental change: the fact that climate means different things to different people in diverse cultures. He argues that climate needs to be conceptualized and presented as a '*manifestation of both Nature and Culture*'. From this starting point, it follows that scientific insights about climate change, although it is a global phenomenon, need to be communicated at the level at which they are experienced: in terms of local weather, and also of how that weather relates to local environments and cultural practices. Like Demeritt, Hulme also gives pause for thought about the position of power – in academic and policy debates – of physical climate science. The failure consciously and deliberately to recognize the cultural context and dimensions of Earth system science means its research products can be appropriated by any of a growing range of ideologies when they are channelled into the policy process: '*Climate change becomes a malleable envoy enlisted in support of too many rulers*' (Hulme, 2008; p. 10). Hulme also points out that the language of the natural sciences, with their complex models, graphs, maps and so on, has more power – what he calls universality and authority – than the generally more context-dependent and context-specific findings of the social sciences, resulting in a narrowed climate policy agenda that excludes other approaches.

Both Hulme (2008) and Demeritt (2001) address the context in which more integrative research is needed, but the *content* of this research is also a focus of debate. At times, it can feel like an impasse between the different methods of the human and physical sciences. The debate is often framed rather bluntly in terms of the contrast between the physical science's focus on