Can Earth System Science be a Valued Element of Fair and Effective Earth System Governance?

DRAFT (20 September 2010)

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Abstract
The hypothesis examined here is that Earth system scientists have become less relevant, or even irrelevant, to Earth system governance. We explore whether this proposition is true and, if it is, why this situation has arisen. By undertaking a review of current national efforts (in the UK and Australia) and a novel proposal regarding the use of the IPCC as a global governance tool, we try to discover under what, if any, circumstances Earth system science is valued in the development of environmental governance. These discussions lead us to the conclusion that targeted Earth system research (e.g. risk and resilience of systems and quantification of benefits of system components) can be genuinely valuable for future environmental governance. We, therefore, invite consideration of how Earth system researchers might be (re-) integrated into global Earth system governance development to the benefit of all.

1. Introduction: Does Earth System Governance Need Scientists?

The environmental challenges facing the Earth today are generally described in recognizably scientific terms, such as, global warming, tropical deforestation and energy depletion, and yet governance solutions seem increasingly to exclude science, or at least to exclude scientists (Guggenheim, 2006; Goodell, 2010). In this paper we explore the hypothesis that Earth system scientists have become marginalized, arguably irrelevant, to recent Earth system governance developments (Royal Society, 2009 cf. Hamilton, 2010). If this is true now, it was not always the case: Aristotle is famous for many contributions, not least as the founder of the first system of formalised reasoning and also for establishing the scientific method as the basis for wise government. This paper is unashamed in its desire to re-engage excellent Earth system thinkers (scientists) with urgently required global environmental governance. We recognise this is not the only route to sound Earth system governance, but we do believe it to be an essential one.

The Open Science Conference on Challenges of a Changing Earth in Amsterdam in 2001 (Amsterdam Declaration 2001) and the Earth System Science Partnership (ESSP) Open Science Conference in Beijing in 2006 (ESSP OSC Statement 2006) called for the development of strategies for Earth system management. In response, the International Human Dimensions Programme on Global Environmental Change (IHDP) launched the Earth System Governance (ESG) project in 2009. The ESG science plan has identified flagship activities on climate, water and food. These flagships are purposefully aligned to ESSP Joint Projects (Global Carbon Project, www.globalcarbonproject.org), Global Environmental Change and Food Systems (www.gecafs.org), and the Global Water System Project, www.gwsp.org). The ESSP Joint Projects aim to elucidate the social and economic challenges caused by global environmental change (GEC) for carbon dynamics, food, water - and more recently - health, and to understand the implications of human-driven changes in these issues for the functioning of the Earth system (Leemans et al., 2009). With these projects designed and arranged to produce policy-relevant science on, for example, greenhouse gas emission reduction, sustainable urban development, governing food systems in the context of GEC, and the responsibility of institutions in adaptive water governance, there seems to be a role for scientific input to governance development (Max-Neef, 2005). Despite this currency of science, it appears to many that Earth system scientists that they have become irrelevant to recent Earth system governance developments (cf. Hulme, 2010).

Manifestations of disengagement are harder to identify clearly than engagement. The recent Royal Society study of ‘Geoengineering the climate: Science, governance and uncertainty’ (Royal Society, 2009) can be viewed either as a plea by geo-scientist to be included in governance or as a leadership statement by Earth systems scientist on the pros and cons of governance options. Two additional and current examples serve to illustrate our lack of relevance hypothesis: scientific response to the Australian 2010 general election (which produced a hung parliament) and to the Inter-Academy Council Review of the Intergovernmental Panel on Climate Change (IPCC) (IAC, 2010). During the pre-election campaign the Australian Federation of Australian Scientific and Technological Societies (FASTS) put a set of questions to the three main political parties (the Liberal-National Coalition, Labour and The Green). The parties’ responses to these questions, released a few days before the election (18 August 2010), caused little media comment but since the polling outcome impasse they have been revisited. The Executive Director of FASTS, Anna-Maria Arabia, spoke quite vehemently on the ABC radio’s Science Show on 28 August 2010 about replies to one of their questions, “Does your party accept that peer-reviewed scientific evidence should be used as a primary source of information in decision-making?” Commenting particularly on the Coalition reply that was “All government decisions should be considered and well informed, and where appropriate scientific evidence and opinion must be consulted.” She said:

> “It deeply troubles me that the coalition responded that (this) was their belief …. Scientists Australia-wide and indeed the broader community are right to feel deeply uncomfortable with a position that places opinion on an equal footing with research and knowledge that has been gathered by some of Australia's most respected scientific authorities, such as the CSIRO. Independent and scientific advice must always be delivered to and heard by governments, not just when it is appropriate.” (ABC Science Show, 2010, transcript p2).

Similarly, while most climate change scientists greeted the IAC review of IPCC’s processes (released on 30 August 2010- IAC, 2010) with a shrug and comments along the lines, “as we expected”, a few, more perceptive researchers pointed to the negative aspects of this and other investigations. These include: further increase in quality-related bureaucracy and failure to probe the most troubling aspects of IPCC’s weak processes. For example, Jay Gulledge from the Pew Center on Global Climate Change comments that the IAC review fails to address one of the most critical issues for IPCC: the evaluation and communication of climate-related risks. Of the IPCC he says, “I don’t think it has done very much at all to advance society’s understanding of the risks” (Nature, 2010, p 14).

Earth scientists who wish to contribute to global governance discussions need to become more fully self-aware (Hassol, 2008; Henderson-Sellers, 2010). For example,

Figure 1 depicts a series of caricatures of scientists moving in governance space; (a) streamlined but without much sense of the 'whole system' challenge, (b) solid contributor who, while carrying a heavy burden is stepping upward without understanding of the possible steepness of the future challenges, and (c) an individual greatly overwhelmed by the steepness of the challenge they face. As this Institute focuses on the 'Distributional Implications for Environmental Change and Governance', we here examine the proposition that the recent marginalization of Earth system thinkers (science researchers) from environmental governance discussions is counter-productive (e.g. Brown *et al*., 2010). Specifically, this paper explores what Earth system research has been found to have value in global governance structuring and what less so. Through this analysis we try to discover what types of future Earth system science may be valuable to governance developments and how these researchers might be re-integrated into global environmental governance discussions.

2. Earth System Science Increasingly Strident on Global Crises

Today the world faces many intertwined natural and human-induced sustainability crises including climate change, food shortfalls, water insecurity and fears about fossil fuel reserves. There is a multiplicity of views on the ways of delivery of 'science' into 'policy' within the framework of governance (e.g. Figure 2). Earth system scientists generate new data pertaining to the world's environmental challenges and robust analysis of the many globally significant systems' crises (e.g. Zhao and Running, 2010). However, while global environmental catastrophes are being clearly identified and well explained by science they are not yet addressed effectively or equitably in governance terms (Rogers & Leal, 2010). This may be because our views of the system (of science, policy and governance) differ or for other reasons (Ereaut & Segnit, 2006). In this section a selected set of Earth system crises are examined from the point of view of the translation of scientific research into governance input (Figure 2).

2.1 Anthropogenic climate change accelerating

Key findings of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) include, "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" and that "most of the global average warming over the past 50 years is *very likely* due to anthropogenic [greenhouse gases] GHG increases and it is *likely* that there is a discernible human-induced warming averaged over each continent (except Antarctica)" (IPCC 2007, p 72). Leading up to the 15th United Nations Framework Conference on Climate Change (UNFCCC) Conference of the Parties (COP-15) in December 2009, 2000 climate scientists from 70 countries met in Copenhagen to present the most up-to-date science findings since the IPCC AR4. Professor John Schellnhuber, Director of the Potsdam Institute for Climate Impact Research and member of the writing team (Climate Change Congress Synthesis Report 2009) lamented that "even if we keep global warming below two degrees, we will still see extreme effects of climate change on our societies, and data collected since the production of the 2007 IPCC Report indicate that several climate indicators (for example, sea-level rise, ocean temperature, glacier-melt, Arctic sea ice melt, ocean acidification) all are changing at the maximum rate projected at the time of the last

IPCC report or even faster" (http://climatecongress.ku.dk/newsroom/synthesis_report/). These conclusions were supported by the ESSP Global Carbon Project when it launched its annual Carbon Budget: Trends and Analysis (Le Quéré et al., 2009) at the UNFCCC COP-15 in December 2009. Key findings included: the efficiency of the natural sinks to remove carbon dioxide is declining; the current fossil fuel emission trajectory is tracking if not surpassing the most carbon intense IPCC scenarios; and that the growth in CO_2 for 2009 will decline by 2.8 percent owing to financial crisis but will begin to recover in 2010.

2.2 Biodiversity decreasing

Key findings of the Global Biodiversity Outlook 3 (GBO 3), published in 2010, highlight "accelerating species extinctions, loss of natural habitat, and changes in the distribution and abundance of species and biomes over the 21st century" (GBO 3, p 7). The GBO-3 also illustrates that the conservation of biodiversity and ecosystem services can be, paradoxically, at odds. Larigauderie et al. (2010) emphasise this in the '2020 targets' proposed by the Convention on Biological Diversity (CBD), stating "as participating scientists in the international biodiversity programme DIVERSITAS, we welcome the draft set of 2020 targets proposed by the CBD. But the targets continue to mix the biodiversity we value highly (that is, the conservation agenda) and the biodiversity we urgently need to secure the benefits people derive from fully functioning ecosystems" (Larigauderie et al., 2010, p 160).

The GBO 3 emphasises the necessity of good environmental governance, asserting that "strong action at international and local levels to mitigate drivers of biodiversity change and to develop adaptive management strategies could significantly reduce or reverse undesirable and dangerous biodiversity transformations if urgently and comprehensively applied" (GBO 3, p 9).

2.3 Food security under threat

Food security is defined as "when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (UN FAO 1996). One of the most pressing and complex challenges of the 21st century is food security, with "accumulating evidence that the food security and livelihoods of hundreds of millions of people who depend on small-scale agriculture are under significant threat from climate change" (CCAFS 2009, p 5). The complexity of the challenge of climate change and food security is further complicated when one considers that adaptation responses to climate change may have negative consequences for food security, similarly measures taken to increase food security may exacerbate climate change. Agriculture and its associated activities also contribute to climate change, by emitting greenhouse gases (GHG) and changing the land surface (CCAFS 2009). According to Ziervogel and Ericksen (2010), adapting food systems both to enhance food security for the poor and vulnerable and to prevent future detrimental impacts from climate change requires attention beyond the tradition focus of agricultural production. Ziervogel & Ericksen add that there are multiple components of food security, particularly those relating to access and utilization, which are threatened by the complex responses of food systems to the impacts of climate change. "Food security can only be ensured and enhanced with a suite of interventions across activities, ranging from production to distribution and allocation. Although many studies have demonstrated the importance of policy and institutional interventions for ensuring food security after a shock, the climate change impacts and adaptation community have been slow to pick up on these lessons" (Ziervogel & Ericksen 2010, p 525).

2.4 Water conflict predicted

Freshwater is in short-supply. Only 2.5 percent of the 1.4 billion km^3 of water on Earth is freshwater suitable for human consumption, most of which is inaccessible (almost 70 percent is stored in glaciers, snow and ice). Our greatest source of freshwater is the 8 million km^3 of groundwater, with only 0.3 percent of freshwater (105,000 km^3) comes from rivers, streams and lakes (UNEP 2002).

One of the important consequences of the rapid growth of global environmental science has been our growing awareness of the linkages, interconnections and interdependencies in the global water cycle. We now realize that the various human and non-human facets of the cycle make up a global water system. The scientific community affirmed this concept in the Amsterdam Declaration of the 2001 Open Science Conference 'Challenges of a Changing Earth'. Along with the recognition of the global water system has come the awareness that human activities are significantly and rapidly changing this system. Changes in the global water system are difficult to understand with simple cause-effect relationships because of the intense and complex linkages and feedbacks between different parts of the system. These changes and linkages also sometimes lead to abrupt changes in water systems such as the eutrophication of coastal aquatic systems, loss of biodiversity, the exceedance of safe water supply in urban areas, or intense competition between different water sectors for remaining water resources (GWSP, 2005).

Key findings from the recently published World Development Report suggest that if interlinkages with water security and other key societal challenges (e.g. energy and food security) is not addressed then local water crises may worsen, accumulating into a global water crisis with which could lead to political insecurity and conflict (UNESCO Water Development Report, 2009).

2.5 Global environmental crises demand effective governance

That global environmental crises demand effective governance is self-evident and yet there is a massive shortfall of policy and legislation around the world. In many, if not all, cases this is not because the science is poorly explained or poorly understood: the inability of Parties to the United Nations Framework Convention on Climate Change (UNFCCC) to achieve a constructive outcome at Copenhagen in December 2009 is only one of many current examples (Copenhagen Accord, 2009). This section has demonstrated that strong and clear science can serve to galvanize governance developments but also that it may become too strident, or even partisan, and thus, inhibit good governance. In Section 3 we explore cases in which sound science has been well used in international legislative instruments and other cases in which equally persuasive science has been less effectively translated into governance tools.

3. Environmental Governance Based on Earth System Science

3.1 Evolution of environmental governance

International collaborative efforts designed to tackle environmental challenges began in the early 1900s, including three agreements to curb the invasive species of *Phylloxera vastatrix* (a North American insect that plagued the French wine industry), five on European fisheries, two on transport of environmental harmful materials on the Rhine, one on birds, and one on species and habitat conservation in Africa. There has since been a multitude of global, regional and bilateral conventions to address ozone depletion, climate change, biodiversity loss, pollution of inland and open waters and the exploitation of wildlife and the 'creeping environmental' (Glantz 1999) degradation of our wetlands, deserts and other habitats (Mitchell 2003).

International environmental agreements (IEAs) are common instruments of global environmental governance. IEAs include multilateral environmental agreements (MEAs) and bilateral agreements (BEAs). "The objective of any MEA is ultimately to change state behaviour to mitigate harmful environmental degradation" (Cumberlege 2009, p307). Over the past fifty-years there been an increase in the number of international policy measures that deal with environmental protection (Andresen & Hey 2005), climbing to more than 400 MEAs by the mid-2000s (Mitchell 2003; Kanie & Haas 2004). Munoz et al. (2009) listed the ten leading MEAs: the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (Basel); the Convention on Biological Diversity (CBD); the Convention on Migratory Species (CMS); the United Nations Convention to Combat Desertification (UNCCD); the United Nations Framework Convention on Climate Change (UNFCCC); the Rotterdam Convention on the Prior Informed Consent for Certain Hazardous Chemicals and Pesticides in International Trade (PIC); the Stockholm Convention on Persistent Organic Pollutants (POPs); the Vienna Convention for the Protection of the Ozone (Ozone); the Ramsar Convention on Wetlands (Ramsar); and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

3.2 Differing perspectives of environmental governance

International environmental legislation can be viewed in two ways: (i) stratifying the laws and agreements into Earth system components e.g., atmosphere (climate, ozone, acid rain); biodiversity (CBD, CITES, CMS, Ramsar); and (ii) organising in terms of whether the legal approach is normative only (e.g. the World Heritage Convention simply lists sites at the international level and leaves action up to nation states) as opposed to normative-plus-process treaties (e.g. CITES identifies species and provides procedural trade restrictions; UNFCCC/Kyoto sets standards and also proposes mechanisms to achieve them).

In exploring these current legislative frameworks we seek to answer the question, "is there one 'best' way in which science (clear thinking based on observational evidence) can most helpfully inform governance or are there many?" For example, the successful normative-process mix in the Montreal Protocol may be entirely inappropriate for the situation now facing negotiators in the UNFCCC where it is difficult to see the best governance framework.

3.3 Can we really measure success and failure?

Multilateral Environmental Agreements have resulted in intricate interlinkages between international institutes and states, "a situation that has given rise to questions regarding the effectiveness and legitimacy of the system of international environmental governance that has ensued" (Andresen & Hey 2005, p 211). The study of international regimes has become a relatively well established field since the 1990s. In most cases, regimes have an increasingly positive impact over time, i.e. initial 'stumbling blocks' require patience by policy-makers (Andresen & Hey 2005: p 219).

Mechanisms set in place to tackle the challenge of ocean depletion and acid rain seem to have been successful, whereas efforts to stop dwindling fish stocks and degradation of marine ecosystems seem to be less successful. One reason is that establishing the most appropriate of 'effects data' is problematic. Some agreements have a "single, unambiguous, and obvious behavioural indicator" (e.g. the 1973 Agreement on the Conservation of Polar Bears), whereas other agreements target a multitude of environmental challenges (e.g. CITES addresses numerous species), or an agreement focuses on behaviours that are difficult to quantify (e.g. Wetlands convention that "promotes the conservation and wise use of wetlands") (Mitchell 2003, p 446). Jackobson & Weiss (1998) and Underdal (2001) conclude that regimes to tackle ozone depletion and ocean dumping of radioactive wastes have been considered successful. Both studies claimed that CITES had not been as successful, whereas other, more detailed, studies (e.g. Sand 1997) have made more positive evaluations of CITES (cf. Mitchell 2003).

Andresen & Hey (2005) contend that "regimes that focus on politically and intellectually 'malign' problems score lower in terms of effectiveness than do 'benign' problems...For example, the characterization of the climate regime as extremely malign by all standards and of the ozone regime in comparison as 'a piece of cake' (Mahlman 1997) goes a long way to explaining the stark difference in effectiveness between these two regimes" (Andresen & Hey 2005, p 219).

3.3.1 Montreal Protocol: a benchmark for success?

"Some regimes fail quite miserably, others do reasonably well, but very few fully and permanently resolve the problems they address" (Mitchell 2003, p 448). According to Gareau & DuPuis (2009), contemporary challenges can infuse reflection on past successes as benchmarks for a better future. For example, it seems that climate policy-makers have looked for inspiration from the Montreal Protocol on Substances that Deplete the Ozone Layer. The Montreal Protocol, the first international agreement on the chemical regulation of pollutants has been ratified by 196 countries around the world (http://ozone.unep.org/Ratification_status, accessed: 10 September 2010). The former UN Secretary-General, Mr. Kofi-Anan, described the Montreal Protocol as "one of the great success stories of international cooperation". The success of the Montreal Protocol has been attributed to effective collaboration between scientists, policy-makers and activists (Liftkin 1994), as well as the adoption of legally binding phase-out schemes with incentives to develop and commercialize alternatives to ozone-depleting substances (UNEP 2008).

3.4 Increasingly complex landscape

Since the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro there have been a multitude of MEAs negotiated, including the Convention on Biological Diversity (CBD), the United Nations Framework Convention on Climate Change (UNFCCC), and the United Nations Convention to Combat Desertification (UNCCD). “Intense negotiations, however, have come at a price. They have spread thin the limited financial and human resources devoted by nations to Global Environmental Governance and created a mess of seemingly unmanageable institutions” (Munoz & Najam 2009, p 1). Kanie and Hass (2004) contend that environmental governance is ‘disjointed’ and that environmental and legal processes are at odds. Reasons for this include, ‘environmental policy-makers find it difficult to grasp “scientific uncertainties”’, ‘incompatibilities between the ethical and political ramifications of the precautionary principle’, ‘international agreements are often negotiated by way of “specific” regimes that are considered in relative isolation’, ‘agreements are negotiated by specialised ministries or functional organizations within forums that are detached from the negotiating arenas of other international agreements’, and ‘the treaty-making process is extremely time consuming’. Moreover, international environmental policy-making has been established in relation to issue, sector or location which has led to treaties that ‘often overlap and conflict with one another’ (Kanie & Haas 2004, p 2). Mee (2005) has observed a shift in the ‘dominant focus’ of the international agenda from ‘environment’ at the Stockholm Convention in 1972, to ‘environment and development’ at Rio in 1992, and ‘sustainable development’ in Johannesburg in 2002 (Mee 2005, p 227). Concerning the expansion of the sheer number of environmental negotiations, Munez et al. (2009) noted negotiation fatigue, particularly pronounced on developing and small countries with limited resources. Pelletier contends that “the persistent failures of international environmental governance initiatives to halt the degradation of the global commons are directly linked to the implicit worldview and assumptions fueling the proliferation of industrial society” (Pelletier 2010, p 220). Okereke (2006), lamented on the inequality and lack of awareness of the needs of the South. He added further that international environmental regimes need to be “responsive to the distributional demands of global sustainability and the equity aspirations of the political South” (Okereke 2006, p 735).

3.5 The intersection of Earth system analysis and governance theory

Earth System Governance is “the interrelated and increasingly integrated system of formal and informal rules, rule-making systems and actor networks at all levels of human society (from local to global) that are set up to steer societies towards preventing, mitigating and adapting to global and local environmental change and, in particular, earth system transformation, within the normative context of sustainable development” (Biermann et al. 2010, p 2).

As environmental governance lies at the intersection of Earth system analysis and governance theory (Biermann et al., 2010), a valid research investigation is into situations when Earth systems science and governance tools converge and those when they appear to diverge. Science is found frequently to be both the cause of a legal issue and the basis for its governance e.g. the Outer Space Treaty of 1967 (UNOOSA, 2010). In considering how new governance tools might be developed it is usual to examine those that exist, as done by the Royal Society in its geoengineering review

(Royal Society, 2009). This noted a wide range of exiting international law pertaining to or which could be modified for geoengineering needs (Figure 3).
We have tried to consider the global governance frameworks presently in use in the context of a Copernican-type revolution in Earth system thinking (Figure 4 and Schnellnhuber, 1999). The limited case study research presented in this section suggests some reasons why Earth systems research and governance structures appear at present to be evolving along non-intersecting paths. These include Earth system science research not being adequately relevant to policy and governance needs; research findings failing to mesh with social institutions e.g. reductions in greenhouse gas emissions and atmospheric concentrations being stated as national targets (Stern, 2006; Garnaut, 2008). We have also found that governance mechanisms into which research results can be placed are widely absent (Schneider 1996 cf. Goodell, 2010). Indeed the Royal Society report comments, "There are serious and complex governance issues which need to be resolved if geoengineering is ever to become an acceptable method for moderating climate change." (Royal Society 2009, p ix)
In Section 4 we consider what, if any, actions might be taken for example under the auspices of the Earth System Science Partnership (ESSP) that could bring scientific research into Earth systems and current global governance paths closer together and ultimately to intersection.

4. Examination of a Proposed Governance Frameworks Drawing Directly on Earth System Science

Architectures for Earth system governance under consideration today (Lowe, 2009; Green *et al*., 2010) may be improved by drawing on underlying research (e.g. Schneider, 2010). It is certainly the case that most Earth system scientists write about the 'need' to involve themselves in global governance development (e.g. Doherty *et al*., 2008). In this section we explore, using two current examples, how Earth scientists might gain traction in governance. The first situation arises when Earth scientists themselves actively try to develop 'bottom-up' goals for integration of their work into international environmental policy and governance. The second case arises when economists develop 'top-down' governance mechanisms from an originally science-derived institution: the IPCC.

4.1 Earth system governance planned by Earth scientists: UK and Australia

We review two current national efforts in the United Kingdom and Australia. Both involve a large number (over 300) of scientists and both have the stated aim of engaging science into government.

4.1.1 UK's QUEST

The United Kingdom's National Environmental Research Council (NERC) established its research programme Quantifying & Understanding the Earth System (QUEST) in 2004 and is holding a finale event in London in November 2010. The scope of this national research programme encompasses the global atmosphere, oceans, hydrological systems, the cryosphere, biological systems, natural disturbance (e.g. volcanic eruptions) and human-induced change and consequences. Over its six years QUEST research has focused on: climate-biosphere feedbacks; natural regulation of atmospheric composition; how much climate change is "dangerous"; and what can be done by managing the biosphere to mitigate climate change?

While QUEST's primary objective has been to improve and increase the qualitative and quantitative understanding of large-scale processes and interactions in the Earth system, there was an explicit additional aim from its inception. This Earth system science research was designed to be relevant to policy-makers, so that the programme established links with UK stakeholders within and outside government. As a result QUEST claims to have developed a stronger UK Earth system science community, with scientists who are now more able to collaborate across disciplinary boundaries to answer questions that are best be tackled by an interdisciplinary approach. QUEST scientists have worked closely with policy-makers and other users of scientific research from the early stages of the research to develop and deliver scientific evidence. It has provided advice and information to many organisations including on historic and future emissions to the UK's Department of Energy and Climate Change (DECC) and the Committee on Climate Change. More importantly synergies have arisen between the science 'push' (e.g. better understanding of the role of land use change in emissions and mitigation) and the policy pull (e.g. need for information at UNFCCC COP-15). Science has also informed business and laws surrounding its uptake – e.g. bio-energy for Volkswagen.

Thus QUEST has been successful in integrating it key research outcomes into governance structures (mostly in the UK) and engaging policy-makers in synthesising knowledge across challenging research-governance/legislative boundaries.

4.1.2 Australia's Decadal Strategic Plan for Earth System Science 2010 – 2020

Australia's Academy of Science has been developing an Earth Systems Strategy for some time and has held a series of consultative meetings with Earth scientists that will culminate in the launch gathering in December 2010. In September 2009, the draft 'Decadal Strategic Plan for Earth System Science 2010 – 2020' created by Australia's National Committee for Earth System Science was discussed in detail. Following this a revised document was developed and this was widely circulated for input and comment. The goal of these interactions was to develop a direction for Australian Earth system science that would not only allow but also positively encourage engagement with policy-makers and governance structures.

In the preface to the Academy draft it is stated that, "the overarching objective is … a coherent, vibrant, evolving and effective community of Earth system scientists in Australia who …... will provide sound Australia-relevant information suitable for helping the wider community's (public and private sector's) appreciation of and capability to adapt to global environmental changes that are under way." i.e. creating and sustaining a role for science in governance.

Despite this earnest desire, the document developed, at least up to mid 2010, falls significantly short of the goal of integrating science into governance. For example we (the authors of this paper jointly with Colin Prentice) have commented as follows:

> "We appreciated this effort to establish a bridgehead for Earth System Science (ESS) in Australia. The document gives good reasons for pursuing trans-disciplinary ESS in Australia, showing that there are important ESS issues of direct concern to Australians. It does a good job of linking the national to the

global scale, and it recognizes the relevance of ESS to pressing policy concerns. We have reservations about the overall usefulness of the document, however, specifically:

- The general approach is by now conventional, and it has failed. ‘Earth system questions’, cutting across the natural-social science divide and broadly similar to those presented here, have been aired in many international forums during the past decade. They have failed to galvanize either the research community or its funders.
- The ‘global-scale overarching challenge’ is too general. Basically it is the Millennium Development Goals. But ESS cannot actually solve the problems in meeting these goals. The potential contribution of ESS is real, but it needs to be defined far more sharply.
- The document is too long and unfocused, and at times reads like a list of people’s ‘pet projects’. The need for ESS is urgent. This message will not get across to funders unless the case is made more aggressively, concentrating on achievable research tools and targets.
- The approach to outreach is outmoded. A biennial conference may be a good idea but it is not innovative. There is a huge opportunity to involve stakeholders in framing and prioritizing questions for ESS. That this opportunity has not been taken is a major deficiency.
- Potential links to the international development community are not explored. As an example, ocean acidification is mentioned as a scientific and environmental problem. Its potential impacts on fisheries have a direct bearing on many people’s livelihoods, but these are sidelined.
- In common with many documents of this genre, drafted by natural scientists, there is a failure to recognize what different social science research communities could contribute. The fundamental division between economics and other social sciences is glossed over, and questions that need economics (e.g. quantifying adaptation costs) are missing.
- The document does not address how an ESS programme might be implemented. This was presumably intentional. But such a document should have a target audience, and it is not even clear what that is. We believe there is a need for a more goal-oriented analysis that would involve academics and practitioners from a much wider background, and would aim to define the specific needs for a funded programme in ESS.” (letter dated: 16/3/10).

The Australian Academy of Science’s ESS project leader, Dr Roger Gifford circulated the latest draft ‘Australian plan to develop a science of the whole Earth system’ (September 2010). The updated Report outlines an overarching global Earth system issue, “How can we secure a well-functioning and resilient Earth system for the indefinite future? The challenge we face is to achieve a stable balance between the needs of the people on Earth and the physical and biological limits of our planet. The goal of Earth system science is to provide the knowledge needed to reach this balance and Australia-focussed Earth system issues”, which include the following issues relevant to environmental governance:

What institutional arrangements must be set in place to ensure long-term sustainable land use in the face of competing social and environmental requirements?

What management options can Australia adopt to minimise the risks of damage from ocean acidification to its iconic coral reef systems and marine biodiversity?

What can Australians do, both institutionally and personally, to minimise the risks and impacts of pandemics in a "globalised" world?

(National Committee for Earth System Science Australian Academy of Science 2010).

The Australian development was similar to that in the UK in its overall aim but not organisationally. The two case studies differ radically in result and process: in the UK the direction was from NERC to scientists 'to engage' whereas in Australia the Earth scientists themselves struggled to figure out how to make the case for this engagement. Overall, even though the former is more successful both are limited.

4.2 Climate governance based on IPCC

Although there are many current environmental challenges, the issue of anthropogenic climate change (global warming) is arguably one of the most urgent (IPCC, 2007; Hamilton, 2010). Global warming, as has been shown here, is also a potentially very useful case through which to evaluate how Earth system science can be translated into the basis for a global governance framework. The United Nations Framework Convention on Climate Change (UNFCCC) is a very odd, arguably unique international convention that was started by scientists and NGOs not by nation states, as is the case for virtually all other UN conventions (Figure 6). Here we examine a recent report that builds on the IPCC's mandate to be 'policy relevant' by proposing that a modified version of the IPCC could metamorphose into a global governance tool (Green *et al*., 2010). This proposal is in sympathy with other, recent, calls for focussed science-based UN agency action (e.g. Economist, 2010).

Green *et al.* (2010) begin by noting that Conference of the Parties (COP)-15 in Copenhagen failed to produce an agreement for mitigation of greenhouse gas levels in the atmosphere or for adaptation to the consequences of human-induced global warming (cf. Copenhagen Accord, 2009). These economists first argue that a price-based framework is essential in order to reduce greenhouse gas emissions and then try to outline how a governance structure could be established. Specifically Green *et al.* (2010) state that the Copenhagen Accord (2009) can be made into a fair and sufficient global process for mitigating climate change by creating: (i) a negotiating forum for carbon price commitments and supporting rules – they propose this part of the overall governance be hosted by the Major Economies Forum (MEF); (ii) ensuring there exists a monitoring, reporting, compliance and publication of information system – this they believe could be managed by the UNFCCC's SBSTA ; and (iii) the establishment of a synthesis and policy advisory body. Green et al. (2010) propose that this structure, which they admit does not currently exist, could be undertaken by an expanded version of the IPCC. The rules that govern IPCC, to which they sadly failed to adhere during the AR4, include making policy-relevant but no policy-prescriptive statements.

Following the allegations of errors (e.g. the melt date for Himalayan glaciers) and inappropriate conduct of some senior members of various IPCC panels and authoring teams (e.g. Michael Mann), the Inter Academy Council (of scientific academies around the world) was commissioned to review the IPCC in 2010 (IAC, 2010). Their preliminary report and findings were discussed at a press conference held in the United Nations on 30 August 2010. At this the chair of the IAC committee, Harold Shapiro, confirmed the importance (for future governance models of Earth system) saying, "The IPCC sits at the intersection of science and policy and, in many ways, it represents a significant social innovation". At the same formal presentation, the current chair of the IPCC, Rajendra Pauchari underlined the strength with which many scientists feel their societal obligations, "Why should we not provide business advice? They have to be part of the change if there is a change." This is the Earth system dilemma: the tension between the need and desire for 'objective science' from highly educated researchers and the certainty of the need for action held by many of these same science practitioners.

The Green et al., (2010) proposal about expanding the IPCC is interesting even though some have argued that once climate change became a risk management problem the approach, structure and challenged integrity of the IPCC become a serious hindrance. The tension between this IPCC prescription and open statement of the views of the scientific community has not been, and may never be, resolved (Schneider and Mastrandrea, 2010). Sadly, during 2009-early 2010 mass media factors changed the IPCC from a well-intentioned peer-reviewed research assessment into a system that is serious hindrance to good governance. The top ten challenges for the IPCC are: its linear structure (first 'science', then 'impacts' and finally, 'mitigation'); its long/slow time frame (the fifth assessment will not be published until 2014 despite that fact that by 2007 the fourth assessment was already out-of-date); its mandated incapacity to make policy statements; the no-preference display of results (i.e. failure to "out" the bad models); the model intercomparison project paradox (gradual improvement in community-wide performance masking serious individual failure such as non-conservation); cost of participation vying with national and laboratory kudos; group fear of highlighting shortcomings and failures (in models and observations); diminishing of fatness of the PDF (probability distribution function) tail; that IPCC has, itself, become a target; and, sadly, "Climate-gate". That IPCC is failing is well known among participants: "adding complexity to models, when some basic elements are not working right (e.g. the hydrological cycle), is not sound science;" and "regional climate is not a well-defined problem. Until and unless major climate can be predicted to the extent that they are predictable, it may never be. If that is the case, then climate science must say so," (e.g. Henderson-Sellers, 2008; Doherty et al., 2009).

The proposal to establish a new three-cornered Earth system governance body built from the MEF, UNFCCC's SBSTA and an expanded IPCC has been examined. We find that Green et al., (2010) concisely illustrate the accomplishments of the UNFCCC since it was negotiated in 1992, e.g. establishing common standards for measuring, accounting for and reporting greenhouse gases and for nurturing improved technical and administrative capacities of developing countries to respond to the challenge of climate change. The paper also succinctly highlights the inherent flaws in the UNFCCC. According to Green et al. (2010), progress was made in Copenhagen and that many of the most powerful countries are determined to take significant steps to cut emissions. Green et al. (2010), however, go on to express that the COP-15 in Copenhagen ultimately illuminated flaws in the climate framework itself, which include the 'comprehensiveness of UNFCCCs scope' (i.e. more and more issues have been added to the agenda and thereby over-laden the negotiation process, rather than breaking down issues into smaller, more manageable components); 'universal consensus' (i.e. any one of the 193 Parties can effectively stonewall progress); 'binary distinction between developed and developing countries' (i.e. 'common but differentiated responsibilities'); and 'targets and timelines' (i.e. countries pledge targets that are in principle motivated by sovereign self-interest). Green et al., (2010) contend that "international institutions and agreements depend for their effectiveness on the voluntary action of States...States should design international institutions and policies that help them overcome their self-interests and realise their collective interests". They go on to add that, "Without public support for emissions cuts, business investment in a low-carbon economy and domestic policy interventions from governments, an effective response to climate change will remain a distant hope" (Green et al, 2010, p 6).

The Green et al., (2010) paper on 'confronting the crisis of international climate policy: rethinking the framework for cutting emissions' is constructive as it not only presents fundamental flaws in the existing climate framework, it also articulates a new governance system to confront climate change. They propose a (carbon) 'priced-based' international framework that is bottom-up, parallel and, yet, independent from the ongoing UN process. When one considers this in the context of Earth system governance and the role of science, the framework that Green et al., (2010) sets forth emphasises the importance of Earth system research and the ongoing desire for up-to-date scientific knowledge. This message resonates with a recent draft paper presented by members of the Global Carbon Project to the ESSP Scientific Committee in April 2010. In this presentation, the GCP noted that the public's support of political efforts to limit global warming "hinges on robust and transparent information from the scientific community" and that "existing institutions that support the science of climate change are not adequate to support the policy needs, particularly for the monitoring and assessment of the earth's biogeochemical cycles" (Le Quéré et al., 2010, p 1).

Regarding the concept of a carbon tax, there have been some promising signs from surprising quarters. For instance, in Australia, the BHP Billiton (global resources company) chief executive advocated a price on carbon (ABC 16 September 2010). It will be interesting to see if the idea of a 'price-based' framework gathers traction. The Green et al. (2010) paper is thought provoking and one that we hope stimulates discussion at the Marie Curie Training Institute in Berlin in October 2010.

This section has examined two ways in which Earth science can be made serve as the basis for governance: at the national level when scientists try to 'envisage' holistic systems into which they 'slot' their science and when an international science-derived structure is co-opted for governance. The latter has some strength while the former seems, at best, limited and, when poorly conducted, doomed. The cases reviewed in this section share an important commonality: the continuing discovery of new Earth system science and its potential importance to governance. In Section 5 we explore specific new science that has been identified as necessary and which may well contribute to (re)build global governance-science synergy.

5. Earth System Research: a Route to Successful Earth System Global Governance

We have tried to discover the circumstances under which Earth system research is valued and from this attempted to propose how Earth system researchers might be re-integrated into governance. In the previous section a positive proposal based around the IPCC seems to offer one way forward. Earlier sections identified another avenue for future governance-science synergy: research into topics of direct relevance for Earth system governance. This begs the critical question, "what Earth system research is required for better global governance?" Doherty et al. (2008) give their sixth 'Key research need' as, "A systematic approach must be established specifically to monitor and assess vulnerability" (Doherty et al., 2008, p 502). They also describe the importance of prioritising scientific research that is "society-relevant" and designed to "address these issues and policy responses" (their figure 1, p 502) which echo the key recommendations of the Inter Academy Council's review of the IPCC (IAC, 2010 - Section 4.2). Larigauderie and Mooney (2010) report on ideas for an intergovernmental science-policy platform built around biodiversity and ecosystem services. These recent reviews all suggest the need for a better mechanism for valuing of 'natural' contributions to Earth systems and a better understanding of the emergent behaviour of coupled natural-human systems. In this section these current Earth system science-demands (resilience and environmental valuation) are reviewed as possible inputs to future Earth system governance instruments.

5.1 Earth system resilience

The concept of resilience has evolved, together with vulnerability and adaptive capacity. All these concepts owe their origins to the meteorological breakthrough in the early 1960s by Lorenz (Lorenz, 1961; Gleik, 1998). Once climate had been clearly seen as characterised by emergent behaviours (e.g. Figure 7) there followed a wave of biological, social and myriad other applications of 'chaos theory'. In time this has come to provide a substantive foundation for what is now termed resilience approaches or 'resilience thinking' (Walker and Salt, 2006). The idea of resilience originates in biology/ecology both of which build on the first revelation of the importance of complex system behaviours (Manson, 2001). The basis is that there are limits to the degree to which a system can cope with a shock, recover and reorganise and maintain similar functionality (Mitchell, 2009). When a complex system passes one of these limits, also called thresholds or tipping points, the system spontaneously self-organises, but in a different direction (e.g. Lenton *et al.,* 2008). "Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state" (Holling 1973, p 17).

In many resilience studies one of the key attributes of a resilient social ecological system, is termed adaptive governance, and distributive governance. As with complexity theory generally, Complex Adaptive Systems (CASs) approaches is a young area that continues to advance (e.g. Gallopín 2006; Janssen and Ostrom 2006; Walker et al. 2006). However, Earth system discussions have developed around the concept of applying CAS theory to social-ecological systems (Adger 2006; Folke 2006; Gallopín 2006; Smit and Wandel 2006). This suggests that just one level at which decisions are made is poor management. Instead is it preferable to try and make decisions at the most appropriate scale, and that level at which disturbance is happening. Research shows that centralising on its own reduces resilience in the system as a whole: centralisation slows feedback and it takes a longer time for some effect to be recognised back at the source, or at the place where decisions are made. In such co-evolving human-social and ecological systems, smaller systems can be nested within larger systems, and the potential exists for bidirectional cross-scale impacts between systems in, and which interact with other social-ecological systems (Berkes and Folke 1998; Gunderson and Holling 2002).

The degree to which resilience theory can inform environmental governance depends on whether intervening in complex adaptive systems is considered wise or even possible (e.g. Waldrop 1994). A science-directs-policy approach is consistent with researchers in the global environmental governance area who ground their calls for thoughtful engagement in social-ecological systems in support of resilience and sustainability. Adaptive management and governance (e.g. Norberg and Cumming 2009) and social learning (e.g. Keen et al. 2005) are examples of such approaches. With particular relevance to anthropogenic climate change in the 'Anthropocene' (though without specific reference), Waldrop (1994, p.320) calls for global-scale agreements and treaties to help steer humanity through future evolution. This section introduces the concept of co-evolution that can also be applied to science in governance.

5.2 Earth system resilience and the Earth System Science Partnership
Under the auspices of the International Human Dimensions Programme on Global Environmental Change (IHDP) – a parent programme of the Earth System Science Partnership - a ten-year Earth System Governance Project (ESG, www.earthsystemgovernance.org) was launched in 2009. ESG draws upon expertise from various disciplines and regions to study the governance of global environmental change. The research programme places emphasis on five interdependent analytical problems: architecture, agency, adaptiveness, accountability, and allocation & access (the five A's). "Within the framework of earth system governance, the term adaptiveness includes the governance of adaptation to social-ecological change as well as the processes of change and adaptation within governance systems" (Biermann et al., 2010, p 3). The Earth System Governance Project examines the five A's (that includes resilience, under 'Adaptiveness') through 'flagship activities' that are linked to the Joint Projects of the Earth System Science Partnership (ESSP): the Global Carbon Project (GCP), Global Environmental Change and Food Systems (GECAFS) and the Global Water System Project (GWSP). The remainder of this section illustrates examples of GWSP, GECAFS and GCP research on the resilience of food and water systems and the carbon cycle, respectively.

The GWSP investigates how resilient and adaptable the global water system is to change and what sustainable management strategies are. Water problems have tended to be considered local or regional problems. Alcamo et al. (2008), however, promoted the need to consider the global dimension. The hydrological system is a global system and exchange processes occur at the global level over relevant time periods (e.g. climate change impacts; other teleconnections, for example, between deforestation and precipitation). Global environmental change and socio-economic phenomena at the global level manifest water-related problems and conflicts that lie outside the sphere of local, national or basin oriented governance regimes (e.g. global trade impacts on water quantity and quality, climate change). Pahl-Wostl et al. (2008) challenge that existing fora and processes of global water governance are inadequate. In their analysis of the current state of global water governance they have observed the disjointed character of today's Global Water Governance with a diversity of players without any sign of global leadership. Despite its scientific and political importance, there has been scant work on water governance and little exchange between academics working on governance at the global level with those working at the basin and community levels. To improve this situation the Global Water System Project (GWSP) has started to establish a community of scholars working on global and basin water governance issues by organizing a suite of activities related to the topic of global water governance.

Investigating the vulnerability of food systems is a central tenant of GECAFS (Figure 5). Its overarching goal is, therefore, to understand the myriad of interactions among food systems and global environmental change processes, starting with the ways in which food systems are vulnerable to current and future environmental stressors. GECAFS research identifies the need "to integrate factors across a food system to assess the system's vulnerability to environmental change by focusing on key processes and system characteristics" (Ericksken 2008, p 14). Liverman, Ericksen & Ingram (2009) identify the following research questions at the intersections with Earth System Governance: (i) how can food governance be designed so as to maximise adaptation and flexibility to global environmental change? (ii) What can be learned from local knowledge and institutions that facilitates adaptation at other scales? (iii) How have major changes in food governance (such as those from public to private sector, or from simple to complex technologies and supply chains), altered the adaptiveness of the food system? (iv) What can be learned from the experience of the Green Revolution and other major efforts to transform food systems that is relevant to earth system adaptation? (v) To what extent will food system adaptation become a focus of earth system governance, including finance flows and technology transfers? These are the kinds of research questions that will be tackled by the Earth System Governance Project under the theme, 'Adaptiveness'.

The single biggest added value of the GCP is the integration of multiple components of the carbon cycle into a coherent and consistent picture, including the natural (e.g. carbon sources and sinks of the natural carbon cycle) and human components (e.g. population, economic growth, carbon intensity of the economy, mitigation strategies). This integration is implemented at the global and regional scales (including urban regions) to understand (i) the drivers of atmospheric CO2 accumulation, (ii) the magnitude of the carbon-climate feedback, and, of particular relevance to environmental governance, and of particular relevance to environmental governance, (iii) points of intervention in managing future carbon trajectories which requires an integration of mitigation strategies and the dynamics of the natural environment.

5.3 Economic value of environment/ecosystem services

The Economics of Ecosystems and Biodiversity (TEEB, 2010) was created as a major international initiative to draw attention to the global economic benefits of biodiversity, to highlight the growing costs of biodiversity loss and ecosystem degradation, and to draw together expertise from the fields of science, economics and policy to enable practical actions moving forward. It is part of a World Bank assessment of the value to the global Earth system of 'free' ecological services. The goal is genuine worldwide valuations although these are typically being built up from local studies.

According to Sukhdev (2009), TEEB's study leader, "the main problem is that ecosystems and biodiversity provide both private and public goods...Furthermore, many natural resources are 'open access' and not covered by property rights or effective national laws or international treaties, which leads to their constant depletion". Illustrative of this trend, Sukhdev goes on to explain that 'open access' and a 'perverse system of subsidies' have rendered two-thirds of fish stocks across the globe over-exploited, and have degraded coastal ecosystems. This threatens both the fisheries industry (income of US$80 billion–$100 billion annually), and the livelihoods of 27 million people who depend on fisheries (the majority are poor, small-scale fishermen). Of grave concern is the fact that more than a billion people (mostly in developing countries) rely on fish as their main or only source of animal protein (Sukhdev 2009, p 277). Another example comes from close to Kampala in Uganda, where a proposal to dam a swamp of about 40 square kilometres, drain it and convert it to agricultural land was contested by economists (IUCN, 2010). Their work showed that this swamp was absorbing the human sewage from the city of Kampala and, thus, operating as a waste treatment facility. Converting the swamp to fields and building a new 'industrialised' waste facility would have cost roughly ten times the rewards from the agricultural output. There is, however, hope out there. Ostrom, for instance, unearthed many cases whereby local communities have developed sophisticated methods that enable the successful management of common property. Sukhdev (2009) goes on to urge governments around the world to provide financial or other incentives to encourage stakeholders to become 'responsible stewards' (Sukhdev 2009, p 277).

This paper explores the hypothesis that Earth system scientists have become marginalized, arguably irrelevant, to current Earth system governance developments (e.g. Section 4.1). Such a disenfranchisement, which has been shown to exist at least in part, is unhelpful as researchers comprise a meritocracy which posses a great wealth of knowledge of important to good governance structures (Schneider, 2010). This section added to the proposals in Section 4 two additional areas in which new scientific research is required in order that Earth system governance can be more effectively developed and deployed. In the final section, Section 6, we draw conclusions from this work and look to a more synergistic relationship between Earth system scientists and those developing global environmental governance in the future.

6. Integrating Science: an Essential Distributional Component of Effective Environmental Governance

Science has not always been divorced from politics as seems to be demanded today (IPCC 2010; Schneider, 2009). Indeed, the father of modern scientific practice, Aristotle, is also considered by many as the originator of ethical political thinking. The question posed in this paper is, "how and in what ways, can science be embraced in governance?" An important danger seems to be that Earth systems science is becoming increasingly vehement in its message about global environmental stress (e.g. Richardson *et al.,* 2009). Some existing environmental governance frameworks, which depend upon Earth systems science have been found to be of real value, while others, apparently similarly based, have floundered. Earth system scientists wish fervently to be part of global environmental governance development and have attempted to establish links into policy and governance communities with a variety of levels of success (Crutzen, 2006; ABC, 2010). Here we briefly reviewed current efforts in the UK and in Australia and, perhaps more usefully, new and positive proposal in which governance elements are derived from Earth system science, the IPCC and UNFCCC, themselves unique global government instruments derived from scientific insistence (push) rather than national benefit (pull).

The seven key Executive Summary recommendations for improving IPCC's process (IAC, 2010) include four of relevance to this paper (our italics for emphasis here):

- Governance & Management: "The IPCC should establish an Executive Committee" … to include… "*three independent members, including some from outside of the climate community*." (IAC, 2010, p 2)
- Review Process: "The IPCC should encourage Review Editors to fully exercise their authority to ensure that reviewers' comments are adequately considered by the authors and that *genuine controversies are adequately reflected* in the report." (IAC, 2010, p 3)
- Characterizing and Communicating Uncertainty: "Quantitative probabilities (as in the likelihood scale) should be used to describe the probability of well-defined outcomes *only when there is sufficient evidence*." (IAC, 2010, p 4)
- Communication: "The IPCC should complete and implement a communications strategy that emphasizes transparency, rapid and thoughtful responses, and *relevance to stakeholders*…" (IAC, 2010, p 5)

The highlighted issues (independence from climate change expertise; identification of 'genuine' controversies; sufficiency of evidence; and relevance) are all areas in which science has difficulty and where governance needs to draw on views as well as facts.

That global environmental change is a complex system and as such exhibits emergent behaviours that are generally unexpected (e.g. Schneider, 2004; Lenton *et al*., 2008; and Figure 7) is increasingly clear. We have related current caricatures of the 'scientist' as a free thinker (Figure 4 (a)), a careful plodder (Figure 4(b)), and an ambitious but rather ignorant scaler of heights (Figure 4(c)) to the Renaissance breakthroughs in astronomical thought. In this period science found itself pitted against governance (mostly in the form of the Catholic church's dogmatic adherence to scripture). While, in our view there is little to be gained from new diagrammatic representations of the way in which science and society interact, the ascendancy of the Keplerian view suggests that scientific viewpoints having merit can be encompassed into governance but can neither control it nor it them. Scientific research can be undertaken to try to reduce the surprises inherent in complex systems (e.g. risk analysis and resilience research). Indeed, environmental risk management has identified aspects of the human-natural system that are least well understood: for example into the quantitative valuation of components of environmental systems and into the resilience of these sub-systems. Such findings can assist in directing Earth systems research as we have proposed here. However, we caution that clarity of thinking alone is unlikely to be sufficient to allow scientists to gain membership of governance discussions (e.g. Hamilton, 2010 cf. Hulme, 2010). "Scientists are the first to recognise that other factors may influence decision-making, such as economic circumstances, but opinion shouldn't be one of those factors." (FASTS Executive

Director, ABC, 2010, transcript, p 2). At all times self-reflection by those involved in these systems is beneficial (Green *et al.,* 2010 cf. IAC, 2010).

It seems inherently sensible to consider that Earth system analysis, based on the best available science, is a vital component of any environmental governance strategy (Royal Society, 2009). However, there are many traps for ‘science’, the most obvious of which is the ‘technology control dilemma’ (Collingridge 1980). Ethical issues and the ‘voice’ of science are also problematical: Earth system researchers tend to feel that science should be given status superior to less expert views (e.g. Schneider, 2010). Additionally, while science (findings) must not be partisan, each scientist may consider the degree of vehemence they choose to deploy in explaining their findings. This paper has intentionally focussed on the means of re-engagement of excellent Earth system thinkers (scientists) into urgently required global environmental governance. The analysis here has illustrated an unintended consequence of attempted Earth systems governance can be reduced participation of Earth system research in policy and legislation and that without the contribution of science the negative consequences of exploitation are much less likely to be avoided. The governance process can be optimised to be scientifically literate and factor scientific evidence into good law making. We therefore conclude that governance mechanisms fostering policy-research synergies are most likely to succeed. Even though this is not the only route to good Earth system governance, we believe it to be an essential direction setting.

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Figure Legends

Figure 1: Cartoons of some ways Earth system scientists behave in governance space: (a) fast moving contributor with little sense of the 'whole system' challenge, (b) solid contributor, carrying the burden of scientific understanding who is willing to climb up relatively unconcerned by future step challenges, and (c) enthusiastic individual, perhaps unaware of being greatly overwhelmed by the steepness of the challenges faced.

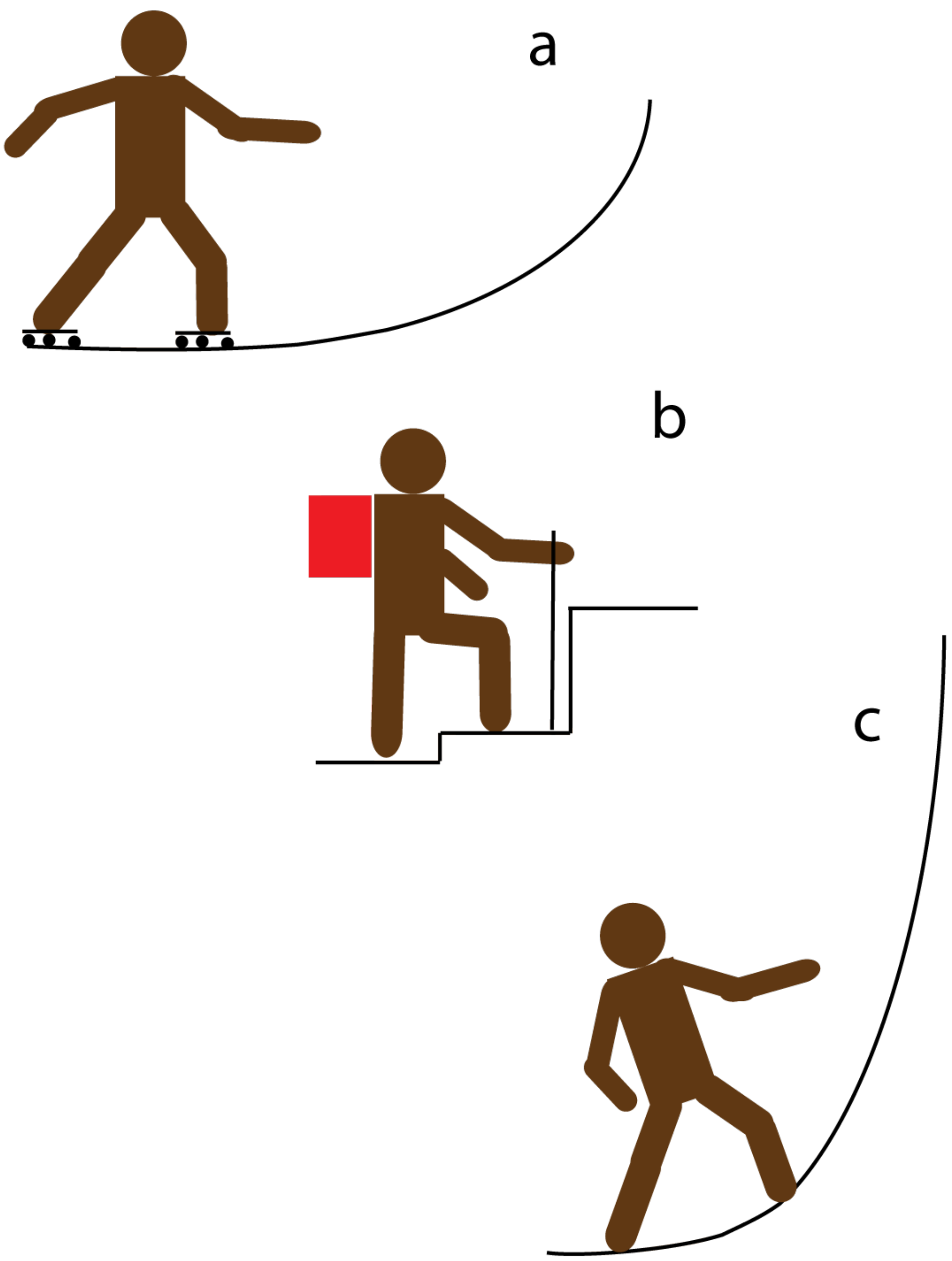
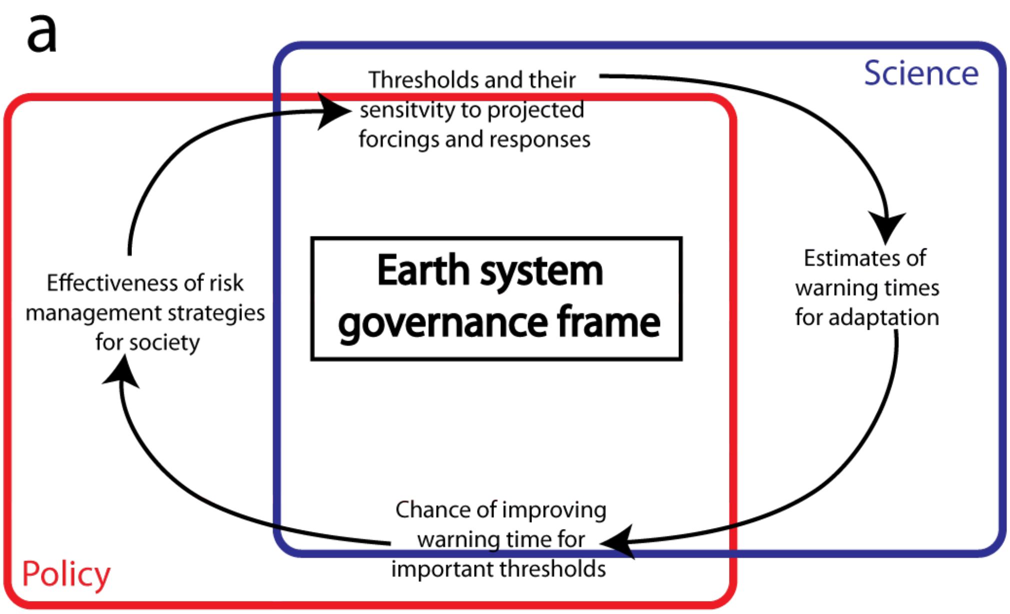


Figure 2: Two examples of many schematics of the delivery of 'science' into 'policy' within the framework of Earth system governance: (a) science and policy as overlapping areas of expertise and activity with governance at their core and (b) scientific and societal research as informing agents at national and international levels and the basis for governance demands.



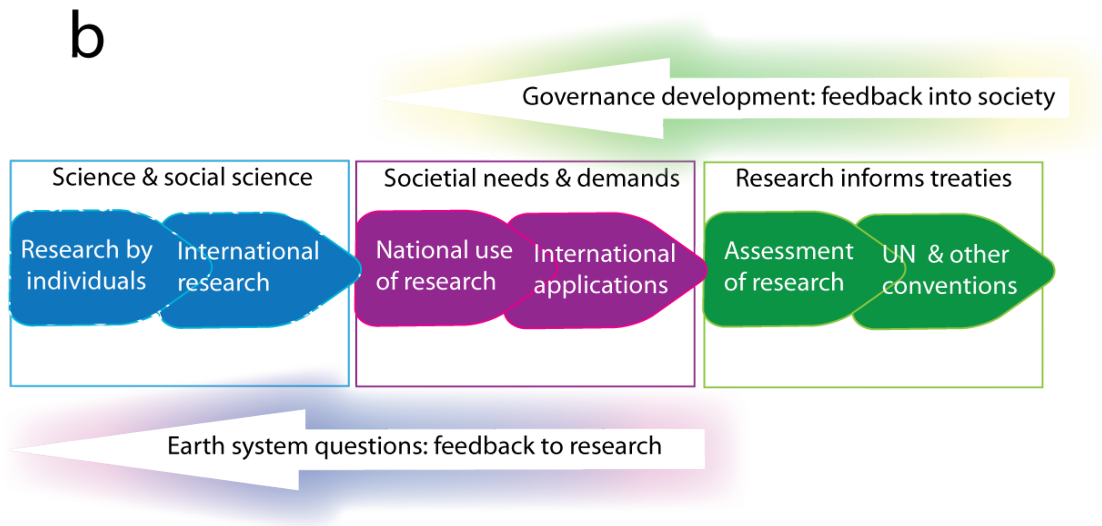


Figure 3: Summary of existing international law of relevance to proposed geoengineering for climate control (source, Royal Society, 2009, p40)

Box 4.2 International law and geoengineering

In addition to the potential application of a range of treaty instruments to geoengineering, there are a number of customary law and general principles which might apply to such activities. The duty not to cause significant transboundary harm is recognised in many treaty instruments (CBD, UNFCCC, UN Law of the Sea Convention (UNCLOS), UN Convention to Combat Desertification (UNCCD)) (Submission: Environmental Defenders Office). States are not permitted to conduct or permit activities within their territory, or in common spaces such as the high seas and outer space, without regard to the interests of other states or for the protection of the global environment. This has the twin prongs of imposing on states the duty to prevent, reduce and control transboundary pollution and environmental harm resulting from activities within their jurisdiction and control; and the duty to cooperate in mitigating transboundary environmental risks and emergencies, through notification, consultation, negotiation and, in appropriate cases, environmental impact assessment (Birnie *et al.* 2009).

This principle does not amount to a prohibition on activities that create a risk of transboundary harm, provided these obligations are observed. In the absence of express prohibition. States are required to exercise due diligence in regulating activities under their jurisdiction and control. Where the activities in question have transboundary implications, or take place beyond national jurisdiction (as would be the case for ocean fertilisation on the high seas and space-based techniques for reducing solar radiation) international cooperation for their regulation will be necessary.

For ocean space, there is the global 1982 UNCLOS, which has widespread participation, and although some States (eg the US) have yet to ratify it, many of its provisions are now reflected in customary international law. UNCLOS applies to all ocean space from territorial waters seawards of baselines out to the high seas. It imposes on States a general obligation to protect and preserve the marine environment, which goes beyond the specific obligations it contains to prevent, reduce and control pollution.

There is no global instrument comparable to the UNCLOS that governs the atmosphere. States have sovereignty over the air space above their territory (and territorial sea) upwards to where outer space commences, although the precise point where this limit is reached is not entirely settled as a matter of law. The injection of aerosols is subject to the jurisdiction and control of the sovereign whose air space it is injected into. Countries must regulate such activities to ensure that transboundary harm is not caused. In addition, regional agreements govern air pollution, such as the 1979 Long-range Transboundary Air Pollution Convention (CLRTAP), which includes a number of protocols on the control and reduction of certain pollutants in the atmosphere, including sulphur emissions. In addition, if one of the effects of stratospheric aerosols is to increase ozone depletion, its injection could constitute a breach of the 1985 Convention for the Protection of the Ozone Layer.

Beyond the atmosphere, the 1967 Outer Space Treaty (OST) preserves outer space for peaceful uses, but does not establish a robust governance structure. States are required to subject the use of outer space to a regime of authorisation and supervision; if an activity or experiment planned in outer space could potentially cause harmful interference with the peaceful exploration and use of outer space, 'consultation' may be requested. The utilisation of dust particles from the moon (and/or other celestial objects in the solar system) would also be governed by the 1979 Moon Treaty. This treaty recognises the freedom of scientific investigation and proclaims the moon and its resources the 'common heritage of mankind'.

Figure 4: Earth science thinkers (parts (a)- (c) from Figure 1) compared with various astronomical views of the solar system: (d) Aristotle and other Greek scientists developed a mathematical description of the solar system with the Earth at the centre of the universe that fully accounted for the motion of the Sun and the Moon and all of the planets as observable to them; (e) Copernicus (a Polish priest) revived an early idea of a Sun-centred solar system believing that it could explain the motion of the planets more simply but his theory was hampered by his belief that all heavenly motions must be composed of uniform circular motions; (f) Kepler by insisting that a solar system theory must fully match observations discovered the elliptical orbits of the planets: a concept even more revolutionary than placing the Sun at the centre of the system.

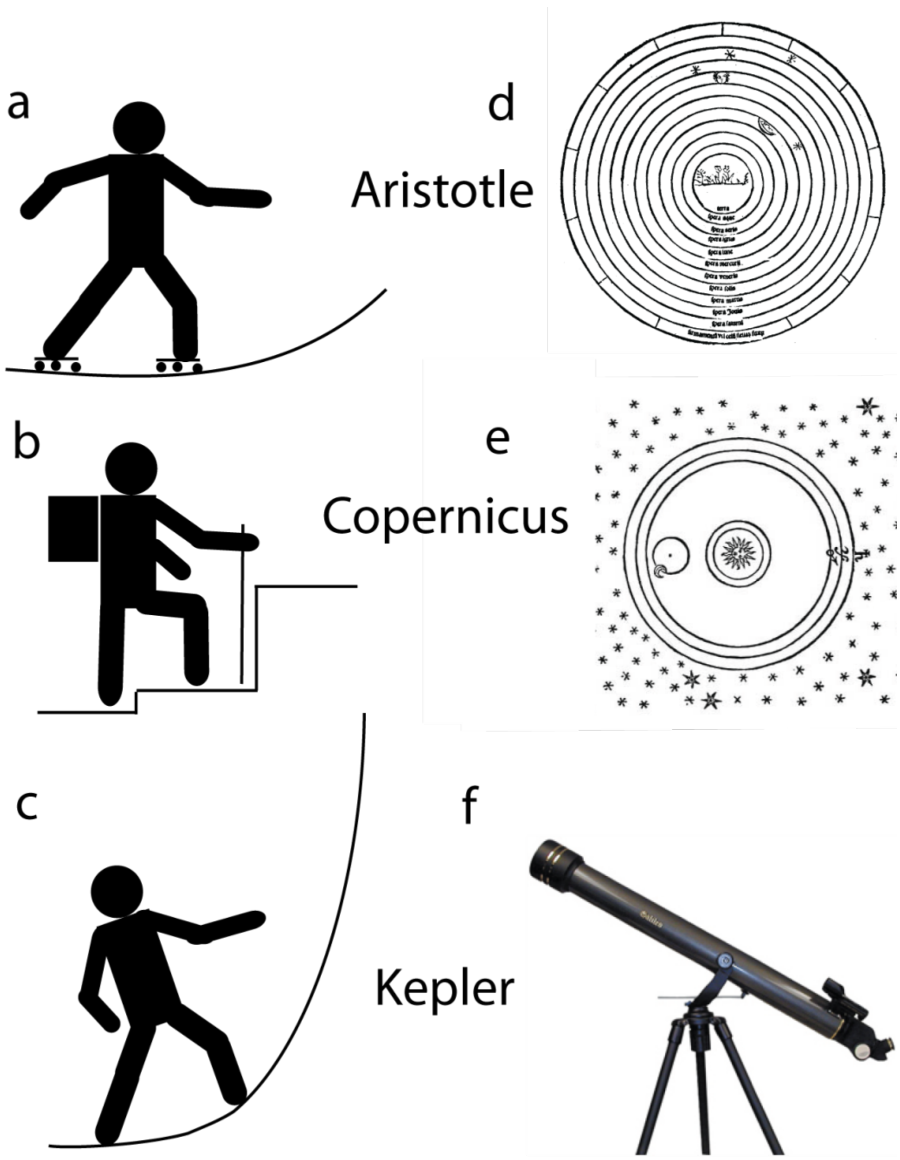


Figure 5 (adapted from Ingram & Brklacich 2006) shows how the vulnerability of food systems is not determined by the nature and magnitude of environmental stress *per se*. It is determined by a society's capacity to cope with, and/or recover from GEC, coupled with the degree of exposure to stress. While the coping capacity and degree of exposure are both related to environmental changes, they are both also related to changes in societal aspects such as institutions and resource accessibility. Finally, changes in the food system aimed at reducing vulnerability feed back to environmental and societal changes themselves. They may, for example, reinforce agricultural practices that either reduce or exacerbate land degradation and increase or reduce farm profitability. The research aim is to enhance understanding of how integrating concepts of food system social vulnerability to GEC with concepts from natural science can provide a more holistic approach to vulnerability studies in the context of GEC (GECAFS Report 1 / ESSP Report 2, p 12).

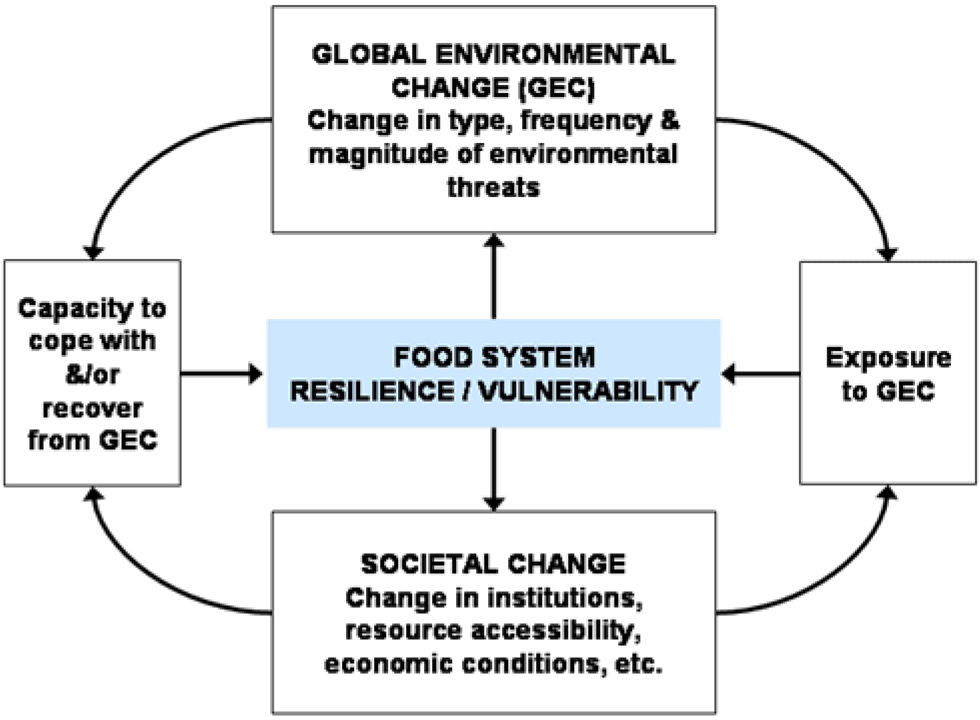


Figure 6: How the IPCC works. The links between science assessment and national government selection of expert authors and review of resulting documents is the basis for Green *et al.*'s (2010) suggestion for a new model for carbon pricing internationally (source IPCC, 2010)

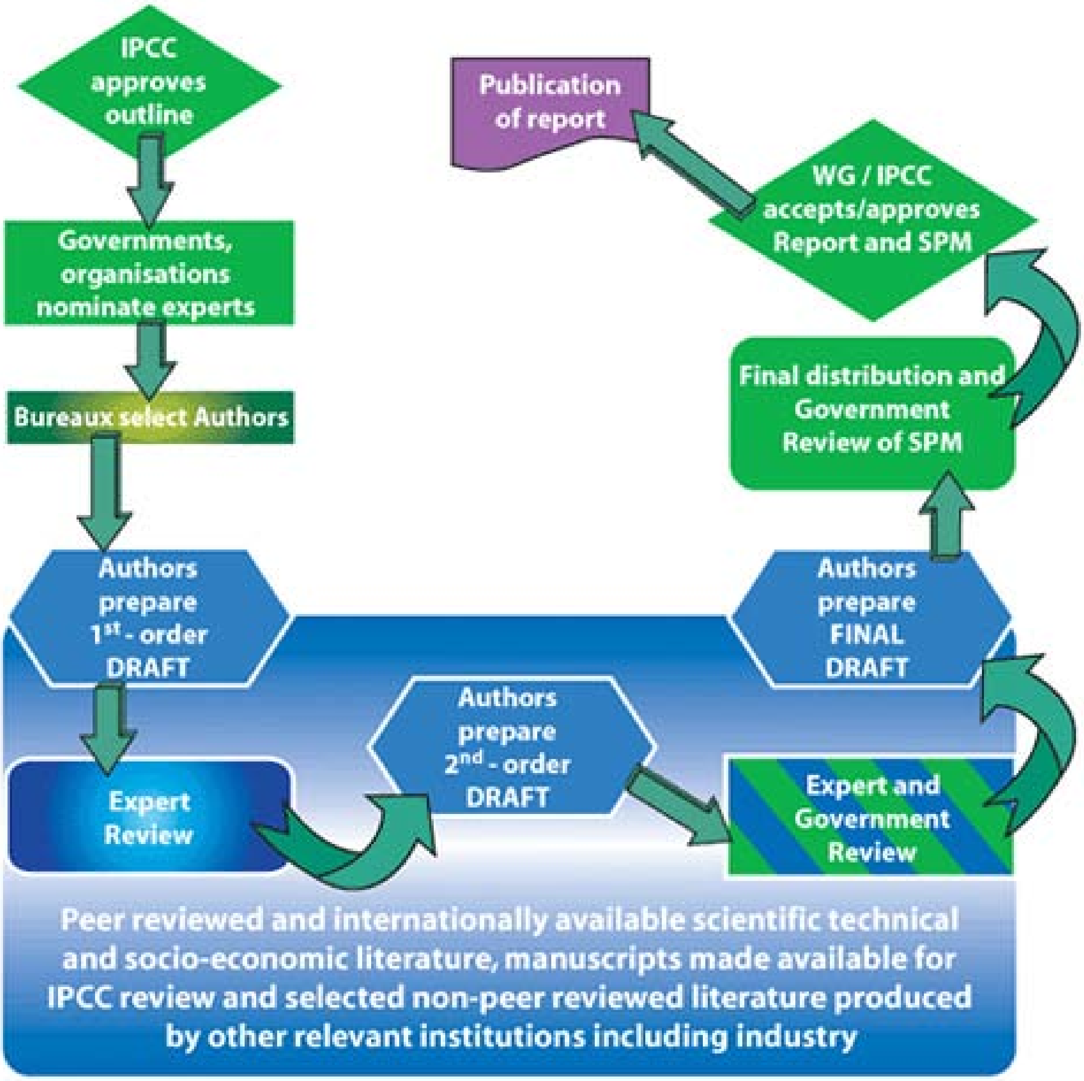


Figure 7: Systems theory shows that all complex systems behave in chaotic ways producing emergent behaviours and 'unexpected' thresholds – for example -the 'Lorenz Butterfly': a Poincaré section, showing the 'climate attractor' for the simple climate model constructed by Edward Lorenz (Lorenz, 1963). The system is characterized by three variables (x, y and z), which pinpoint the state of the system in a three-dimensional space. The apparently disordered behaviour (termed 'emergent') of the system in the upper graph conceals the structure that is beautifully displayed when the system is examined in three dimensions (lower right). Since the system never repeats itself exactly, the track never crosses itself (after McGuffie & Henderson-Sellers, 2005).