Global Change Science: A Revolutionary Approach in Climate Change Research

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Abstract
Climate change is a most challenging research topic, as it is not only an environmental issue but has extensive socio-economic moral and ethical dimensions as well. The underlying processes that drive climate systems are so deeply interwoven with the structures of modern societies that there is simply no hope of easing the anticipated problems without a holistic scientific approach involving entire human societies. There is a need to integrate the environmental science and socio-economic research and to fill the gap between scientific results and decision making at all levels, from the individual to national and international policy. A new research approach, global change science, is therefore proposed. Rather than taking human influence as an external input factor, we should consider it as an integral part of the global ecosystem. This approach is highly demanding, and composing a quantitative model may prove very difficult. Collaboration between at least four types of specialists is needed: 1) "traditional""scientists in various disciplines, 2) "horizontal scientists" to comprehend the spatial human-nature interactions, 3) "futurists" to envision potential trends in the society, and 4) "modellers" to build the model scenarios. This effort cannot be undertaken on national bases and there is, therefore, an urgent need to establish an internationally funded and coordinated global change research unit.

Living with Uncertainty

Climate change is widely considered the most severe of all environmental problems. There is real concern that by the middle or the end of the 21st century human activities will have changed the basic conditions that have allowed life to thrive on earth. The 1992 United Nations Framework Convention on Climate Change (UNFCCC) is one of a series of recent agreements through which countries around the world are banding together to meet this challenge. Climate change is a most challenging research topic, as it is not only an ecological issue but has entered extensive socio-economic moral and ethical dimensions. Despite the unquestionable scientific evidence of anthropogenic interference in the climate system, as presented in the Intergovernmental Panel of Climate Change Third Assessment Report (IPCC 2001), there has been insufficient political determination to tackle the climate change problem, as evidenced by the difficulties in the UNFCCC Conference of the Parties (COP) negotiations in The Hague, and lately in Bonn, about emissions reductions.

The issues in the climate change negotiations have expanded from "simple" emissions reductions to questions related to biospheric carbon sinks (trees, soils, etc.) and to various flexibility mechanisms to cut down the economic burden predicted to result from measures to reduce emissions. In addition to natural scientific issues, social and economic issues such as equity in space and time, as well as over generations, have filled the agenda. Consequently, the research effort in the climate change sector is clearly facing a new, unprecedented venture. There is a need to integrate environmental science and socio-economic research and, most importantly, fill the gap between the scientific results and decision making at all levels, from the individual to entire societies. Another overwhelming challenge is to find solutions to the problems in the Third World (e.g., population expansion, land degradation, uncontrolled urbanisation, health concerns (e.g., HIV, malaria) and gender inequality, to mention a few), which are due to intensify, with or without climate change.

A new research approach, global change science, is therefore proposed here as a potential way ahead. This paper aims to outline some of the essential factors in the new, holistic global change science and to discuss the following aspects of the climate change topic:

1. Assessment of a "good climate;"
2. Global change science: a holistic research approach; and
3. Who governs (and should govern) the global climate?

The complexity of climate change effectively keeps the issue incomprehensible to the layperson. In everyday life, we do not experience climate per se as much as successive weather events and, therefore, the whole idea of climate change is abstract. Contradictory media coverage, which may, for example, suggest that specific weather events such as storms or blizzards are an indication of climate change, may generate irrational, ill-advised fear among the public. We need, therefore, to examine climate change from a public-perception point of view as well.

Good Climate

Climate is a continuous process rather than a (semi-) constant condition of the Earth. Based on a wealth of various proxy data, we know that global climate has fluctuated simply by natural forcing between warm and cool in gentle trends, and also rapidly in flip-flop changes (Adams et al. 1999). Hence, there is no reason to expect climatic stability in the future, although the period since the Agricultural Revolution (the last 10,000 years, or the Holocene epoch) has proven to be reasonably unchanging compared to earlier periods (Petit et al. 1999), with potential slight millennial-scale variations (Bond et al. 1997). A fundamental problem in the understanding of climate change process is the uncertainty of the spatio-temporal details of the anticipated change.

The relationship between the warming of global climate and the climate and weather events at regional or local scales is still largely to be unravelled, despite the sophisticated model-based simulations. The uncertain response of the North Atlantic thermohaline circulation to atmospheric forcing, for example, raises questions of the heat transport capacity of the Gulf Stream in the future. Depending on the response, Northern Europe may, in principle, experience cooling despite rising global mean temperature. Public perception is already saturated with numerous threat scenarios of floods, droughts, storms and other catastrophic events. For many individuals living in cool climates, for example in Canada or in Northern Europe, climatic warming would appear a welcome alteration—a naïve perception of a slightly more "Canary Islands type" climate. Similarly, humidity is generally preferred to aridity. Evidence of these preferences can be found in the concept of the so-called climatic optimum (Oxford Dictionary 1999). During the Early and Mid-Holocene, ca. 8000-6500 years ago, a somewhat warmer climate sustained in Northern Europe (Seppä & Birks 2001), and several temperate plant species such as beech and oak were more abundant in Fennoscandia during this period. Simultaneously, the Sahara was more humid than at present (Claussen et al. 1999; deMenocal et al. 2000). This period is, indeed, often referred to as climatic optimum even in scientific palaeoclimatic literature (nowadays more correctly called the hypsithermal, or the Holocene warm period) despite the fact that from the nature's point of view such rating of better and worse climates is impossible. Nevertheless, one could argue that due to the predicted climatic warming, we are now heading towards another climatic optimum. So what's the problem?

In the developed world, societies have developed infrastructures that are (near-) optimally suited to the present climate: energy production and distribution, building standards, types of agriculture and forestry etc. are fit for the present conditions. Western societies will also have the economic potential to cope with environmental changes and thus, some scientists (e.g. von Storch & Stehr 2000) argue that the actual impact of climate change may prove insignificant. However, any change in climate will require adaptation measures and investments. Therefore, notwithstanding the actual outcome, societies consider any change unwelcome and frightening whatever its nature, be it temperature or humidity. The same holds true on an individual level: individuals are afraid of changes that they cannot control. A paradox lies in the fact that we are intentionally altering the environment with unprecedented haste while simultaneously expecting natural permanence.

The case is quite the opposite in the Third World and in cultures directly dependent on the environment, e.g., hunting and fishing cultures and nomadic peoples. In the Sub-Saharan Sahel region in Africa, for example, where strong climatic fluctuations are common phenomena (e.g. Raynaut 1997), the peoples have traditionally migrated from one region to another, escaping unfavourable conditions. At present, national borders between independent states hinder nomadism, leading to overpopulation, overgrazing and land degradation during unfavourable climatic periods. Similarly, hunting and fishing cultures of the Canadian Arctic are forced to adapt to changes in diminishing ice conditions.

One can argue that despite cultural evolution, the human species still retains the natural instinct to maximise the use of available resources. Due to our limited understanding of the time scales and processes operating in the global ecosystem, we do not seem to be capable of perceiving the limits of growth before they have been exceeded. We have not learned much from lemmings.

Global Change Science

Climate change is without doubt not only a natural scientific problem, but a complex of scientific observations and modelling outputs, public perceptions, socio-economic processes, development issues, equity and juridical matters. Looking back in time, one can clearly see the evolution of various environmental concerns from specific, narrow problems to vast global systems. The environmental concern was, in many respects, born during the Vietnam War and in the nuclear threats of the 1960s, followed by problems such as acidification and ozone layer depletion in the 1970s. More or less simultaneously, the drought and hunger crises in the Sahel opened the eyes of the developed world to the environmental and socio-economic enigma of the Third World. Gradually, the scientific evidence of rising global temperature and its relation to anthropogenic greenhouse gas emissions accumulated, triggering international concern, which culminated, for the first time, in the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992.

It is, therefore, discouraging that almost a decade has passed without much progress in solving the problem, although both scientific research and political negotiations have vastly expanded. In many cases, positive attempts to heal the environmental problems have been contradictory. For example, attempts to encourage carbon sequestration by establishing rapidly growing monoculture forests challenges local biodiversity. Environmental management strategies do not appreciate the ecosystem dynamics but work on short-term reactive approaches. Only lately have the international conventions, e.g., the Convention of Biodiversity (CBD 2001) and the Convention on Climate Change (UNFCCC 1992, 2001), started to interact and approach each other with practical solutions.

The success of international environmental agreements has often been emphasised using the "Montreal Protocol on substances that deplete the ozone layer" from 1987 as a landmark. This has indeed been very successful agreement in cutting down harmful emissions. However, exchanging harmful chemical compounds with less damaging ones is just a technological manoeuvre. Climate change is different. A simple technological solution does not exist. There is a need to make a U-turn in the way the societies operate altogether. Even if we did, say, have the capability to substantially cut CO2 emissions from energy production and traffic, we would still be faced with questions of population growth, natural resource depletion, pollution, urbanisation, food production, poverty, inequality and globalisation, to mention a few. This is what makes global change such a challenging issue. We are forced to challenge our own lifestyles and widen our perspective from local to global in order to grasp the issues of long-term global sustainability.

The underlying processes of climate-driving forces are so deeply interwoven with the structures of modern societies that there is simply no hope of easing the problems without a holistic, scientific approach covering the entire globe. This proposed "global change science" procedure requires a revised fully coupled system analysis of both natural and human systems and their interactions. Attempts and suggestions in this direction have arisen lately by, for example Schellnhuber (1999) who has referred to the concept as "Earth system" analysis (See Figure 1).

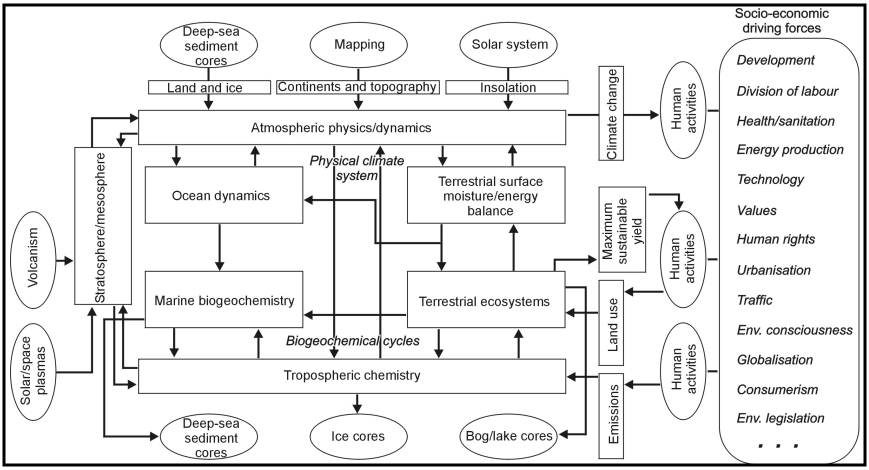

Figure 1. "Earth system" analysis, after Schellnhuber (1999).

Similarly, Lawton (2001) calls for a new Earth Systems Science (ESS) in his Editorial article in the Science. A more comprehensive understanding of the operation of the Earth machine is indeed crucial. There is still very limited knowledge of the regional patterns of climate change, or of potential ecosystem responses. This information is highly relevant in the current socio-economic ethos, which pushes nature to its limits for maximum yield. Socio-economically, however, the "Earth machine approach" is undoubtedly somewhat handicapped. The conceptual model (see Fig. 1) completely lacks details of complex human activities. It concentrates on observing nature's response to the anthropogenic input—merely listing the patient's symptoms. Ecosystem responses are non-linear and therefore, currently emerging symptoms will, rather, reveal the history of unsustainable development and may not be of needed predictive value.

We ought to continue building models of the operation of the socio-economic system plus its interaction with the nature. Rather than taking human influence as an external input factor, we should place it in the middle of the global ecosystem—as an integral part of it. This approach is highly demanding, and composing a quantitative model may prove very difficult. Human societies cannot be predicted: economic progress of business enterprises and the outcome of democratic elections, for example, always exhibit a degree of surprise and unconsidered factors. Although nature operates rather more deterministically in its physio-chemical and biological processes, it also carries a degree of unpredictability, referred to as self-organised criticality, or SOC (e.g., Bak 1996). Earthquakes and the biological evolution as a whole, for example, cannot be predicted even though they are not fully chaotic either; the systems are self-organised. Similarly, many anthropogenic activities, such as the stock market, seem to follow the SOC pattern. Modelling the global natural-anthropogenic system appears therefore unrecoverable with the current knowledge. However, despite the problems in forecasting the systems, the effort to analyse anthropogenic and natural systems simultaneously is desperately needed.

Perhaps the nearest practical analogue to the theoretical approach of global change science can be found in the Special Report on Emission Scenarios (SRES) of the IPCC work (Nakicenovic & Swart 2000). These scenarios are grouped into four specific groups, so called storylines, which stretch between two end-member approaches, global vs. regional and economic vs. environmental. Altogether, 40 scenarios, or possible futures, have been built using six different models. All the scenarios are equal in the sense that no probability or likelihood has been assigned to them. In the context of the global natural-anthropogenic system, building the network of the processes, quantifying the interactions and coming up with scenarios can be considered a new discipline—global change science. The methodology is largely similar to any process modelling approach, but with a high number of unpredictable components and interactions. The individual modules of the system fall into fields of numerous traditional scientific disciplines such as astronomy, economy, atmospheric sciences, law, ecology, chemistry, physics, oceanography and philosophy, to mention a few. The horizontal approach of the global change science actually recalls that of geography, which has been defined as the study of humans' interaction with their environment. Global change science, however, differs from traditional geography by the highly quantitative, modelling-oriented methodology.

Global change science calls for a new type of scientific approach: a fully coupled model of the Earth's natural and anthropogenic processes, i.e., an understanding of the functioning of the global ecosystem. At least four types of specialists are needed to make the analyses run successfully: 1) "traditional" scientists in various disciplines to deepen the current understanding of the processes of the nature and the society, 2) horizontal scientists, "geographers", to comprehend the spatial human-nature interactions, 3) "futurists" to envision potential trends in the society, to decrease the uncertainty aspect and

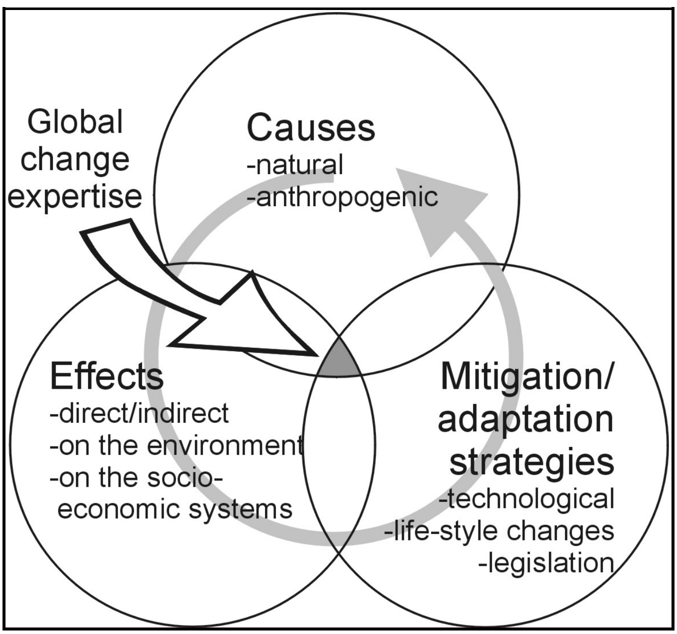

Figure 2. Global change processes.

to fill the gap of unpredictability, and 4) "modellers" to build the scenarios based on the knowledge fed by the former three groups. The expertise needed to unravel the global change process can be found in the midst of the spheres of causes, effects and mitigation/adaptation strategies (Fig. 2).

All the above types of specialist exist at present, but they do not have the necessary infrastructure to collaborate satisfactorily. We do not, however, offer training to become a "global change scientist." In addition to the specialists listed above, we need global change scientists with a broad view to co-ordinate the research and unravel the complex links and processes between human and natural systems. Perhaps this is what geography as a discipline could offer, as suggested by Abler (2001). Various national research programmes have been established world-wide, aimed at encouraging interdisciplinary research, but the scale of the global change problem calls for international research action. The current organisation of international research programmes, on the other hand, clearly indicates the problems in conducting global change research. The topic has been divided between four major international programmes co-ordinated by the International Council for Science (ICSU): the International Human Dimensions Programme on Global Environmental Change (IHDP 2001) on socio-economical aspects and sustainability, the International Geosphere-Biosphere Programme (IGBP 2001) on the ecosystem processes, the World Climate Research Programme (WCRP 2001) on climate research, and DIVERSITAS (2001) on biological diversity. A major step towards a true global change science was taken in July 2001, when a global change science conference was organised in Amsterdam jointly by three of the programmes. There is indeed an urgent need to establish a co-ordinated international research and training unit to tackle the global change. One option would be to refine the IPCC work and bring it under one roof with increased international funding. Care should be taken, however, that such an operation would not hamper the current openness of the IPCC work.

Who Governs the Environment

Scientific results may be disregarded or at least not fully utilised in decision making. As paradoxical as it may sound, the paradigm of self-correcting peer review science may actually weaken the authority of science in public perception, as researchers are not expected to announce their results as definite or absolute. In climate change issues, there is continuous scientific research going on about numerous processes and their interactions. Papers published in scientific peer-review journals may be misunderstood and therefore quoted erroneously by the media. The degree of uncertainty can be used as an excuse for ignoring the scientific results in decision making, as happened in the spring of 2001 when George W. Bush announced that USA would not ratify the Kyoto Agreement.

The missing link between the scientific research results and their utilisation in decision making might partially emerge were an international joint venture of Global Change (or Earth System) Science to be established. One has to appreciate the fact, however, that global change will never be wholly understood. This is why we must not ignore the principle of caution; establishing "minimum safety standards" for operating the Earth, as Schellnhuber (1999) has stated. Decision makers must learn to operate with imperfect knowledge. Neither can global change ever be fully controlled even if certain processes and interactions were understood.

An important issue is who should govern the global environment. Is governance the job of an individual, a nation, or should there be fully global governance? What is good for one may be bad for another. What if political systems lose the global governance to business enterprises, as many anti-globalisation activists nowadays fear? Some scientists believe that participation of the private sector is a prerequisite for sustainable development (Daily & Walker 2000). The crucial question is whether the citizen consumer behaves any differently from the citizen voter. Although many indicators of poor living standards can be assessed, no science can define the good life. Despite all effort, the world will never become problem-free. Global change science has as much to do with morals and ethics as with economy, ecology and atmospheric sciences.

Note

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