Environmental Modelling & Software 44 (2013) 1–9

Contents lists available at SciVerse ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Innovative approaches to integrated global change modelling☆

Carlo Giupponi[a,*], Mark E. Borsuk[b], Bert J.M. de Vries[c], Klaus Hasselmann[d]

[a] Università Ca' Foscari di Venezia – Dipartimento di Economia, S. Giobbe 873, 30121 Venezia, Italy
[b] Dartmouth College, Thayer School of Engineering, 14 Engineering Drive, Hanover, NH 03755, USA
[c] Planbureau voor de Leefomgeving (PBL), P.O. Box 303, NL-3720 AH Bilthoven, and Department of Geosciences, Utrecht University, Utrecht, The Netherlands
[d] Max Planck Institute for Meteorology, Bundesstraße 53, 20146 Hamburg, Germany

ARTICLE INFO

Article history:
Received 10 August 2012
Received in revised form
20 January 2013
Accepted 24 January 2013
Available online 1 March 2013

Keywords:
Global change
Integrated assessment
Modelling
Research priorities
Innovative approaches

ABSTRACT

Integrated models are important tools to investigate the interactions between planetary processes and the growing impacts of human populations – in short: global change. Current models still have significant shortcomings, notably in their representation of socio-economic processes and the feedbacks between these and the environmental system. They are also often not designed with sufficient transparency to enable participation of interested parties or effective communication with stakeholders and policy makers. These deficiencies are discussed and possible directions for improvement are identified. This Thematic Issue provides a collection of papers that offer a number of innovative ideas for remedying these shortcomings using novel methods and approaches.

1. Introduction

Global change is a broad term, encompassing many different but related phenomena of both natural and anthropogenic origin that affect the evolution of the Earth system. Examples of major interrelated global phenomena include climatic change and land use change. The term 'Earth system' emphasises the analysis of the planet as an integrated system of interacting elements (oceans, continents, atmosphere, human societies, etc.) and processes (photosynthesis, anthropogenic emissions, etc.). These can be local in nature, but can also have important consequences at higher spatial scales. Global environmental change refers to the subset of changes with a magnitude or relevance at a planetary level, primarily affecting ecosystems and natural resources but with significant space and time-dependant impacts also on social and economic systems.[1]

Global change problems are multi-faceted. To address the many human-dimension aspects, they must be considered from multiple disciplinary perspectives, including not only the natural sciences, but also equally the social sciences. With the growing awareness by the public and policy makers of the major dangers of global change – manifest as climate change, biodiversity loss, water scarcity, desertification, and stratospheric ozone loss, among others – there is also an increasing demand for scientists to interact more closely with stakeholders and policy makers in developing an effective response to these global threats. This need has become all the more urgent due to the stagnation in international climate policy since the substantial failure of the Copenhagen climate negotiations in December 2009. This has been further compounded by the political and economic dislocations of the concurrent global financial and economic crisis. Both have distracted policy makers from vigorously pursuing the longer term problems of global change. Yet the problems are intimately connected. An effective redirection of investments away from carbon-based and other non-sustainable technologies towards sustainable green technologies can be achieved only if governments understand and are able to effectively stabilize and reorient the financial and economic system.

The current withdrawal of policy makers and even the media from seriously addressing the problems of global change stands in marked contrast to the concerns of the public. In essentially all countries, whether industrial, emerging or less-developed, the majority of the population shares the concerns of environmental scientists for the future of our planet. This is further evidence of the

☆ Thematic Issue on Innovative Approaches to Global Change Modelling.

* Corresponding author. Tel.: +39 041 2349126; fax: +39 041 2349176.
E-mail address: cgiupponi@unive.it (C. Giupponi).

[1] In this article, we do not make a strict distinction between global change (GC) and Global Environmental Change (GEC). In general, we use the term global change in the broader sense of a system that includes social, cultural and political processes.

1364-8152/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.envsoft.2013.01.013

complex relationship between people's personal risk perception and the ability of democratic societies to implement specific political actions in response to scientific risk assessments (see e.g. Leiserowitz et al., 2006).

The importance of models for developing insights into global change and making projections into possible futures is undisputed, as is their potential for communicating scientific knowledge and supporting policy (Harris, 2002). Nevertheless, as recently pointed out by Akerlof et al. (2012) for the US at least, it seems that when models appear in the media – and they rarely do – it is often to question their reliability. The debate between climate scientists and so-called climate sceptics is an outstanding example (Hulme, 2009). It reflects a broader change towards a postmodern society in which neoliberalism and globalization give rise to value relativism and a more short-term orientation (van Egmond and de Vries, 2011). But it is also an expression of the feedback between the media and the public. Rather than repeating the never changing warnings of serious scientists to a tired public, the media prefer to amplify the alternative non-scientific views of sceptics in the scientific debate (Hasselmann, 2010). On a more fundamental level, the financial crisis has had the effect of not only distracting policy makers from addressing global change, but has also undermined the credibility of mainstream economics and its models, which singularly failed to predict the crisis. These developments have resulted in a corresponding loss of confidence of the public and policy makers in the assessments of global change provided by the scientific community. In parallel, citizens and policy makers have realized that there is a mismatch between the science of global change, in particular with respect to climate, and the desire for definitive guidance on priority societal issues, such as potential impacts and damages of climate variability and extreme events on regional and local scales.

To consolidate its role, or to regain lost confidence, it is essential that the scientific community analyses both the successes and shortcomings of existing global change models and then develops new approaches that overcome the identified shortcomings. The purpose of this Thematic Issue is to present a number of innovative approaches that we believe make progress towards alleviating the present limitations of global environmental change models and analyses, thereby opening a new perspective on a more fruitful interaction between global change scientists, the public, stakeholders and policy makers.[2]

2. Integrated modelling successes

Let us begin with the successes. The public's awakening to problems regarding the sustainability of a growing world population and economy can be largely attributed to the widely read and much discussed 'Limits to Growth' report of the Club of Rome (Meadows et al., 1972). This was based on a conceptually easily understood system-dynamics model, World3, which was driven by so called 'stylized relationships' derived from empirical datasets. World3 demonstrated how simulations of various possible development paths could lead to a collapse of the planetary system, as a consequence of phenomena such as over-population and pollution accumulation. The simulations also suggested that, with prompt implementation of sustainable development strategies, alternative future equilibria were still possible.

This work stimulated many further investigations, branching into more detailed representations of the natural bio-geo-chemical system, the climate system, the global energy system and the world economy. A new stream of *Integrated Assessment Models* (IAM) thus emerged. Integrated assessment (IA) can be defined according to The Integrated Assessment Society (TIAS) as "the scientific 'meta-discipline' that integrates knowledge about a problem domain and makes it available for societal learning and decision making processes".[3] This requires the engagement of both stakeholders and scientists. The engagement must necessarily be interdisciplinary, since socio-economic and environmental problems do not respect disciplinary borders. An IAM thus represents a model integrating different disciplines in a transparent and interactive framework. While the scale is usually global, model calibration and validation must often occur at the regional or local scale because of limited global data availability and process understanding. To achieve more effective science support of policy decision processes, IAMs of global change are increasingly being produced in a participatory modelling mode in which the conceptual models and values of stakeholders are translated by scientists into model representations (Parker et al., 2002; Carnevale et al., 2012; Laniak et al., 2013).

Advances in computing power, data assimilation and simulation software have led to significant progress in IAMs of global change over the last forty years. Better datasets are available on changes in emissions of greenhouse gases and other pollutants, on atmospheric composition, and on land use and land cover. There is also a better understanding of the fluxes of the major biogeochemical elements (C, N, P…) in the biosphere and of the physics and chemistry of the earth's climate. Innumerable integrated modelling exercises have been carried out over the last decades in various fields of global change science, including land use, energy production, and technological development. With the use of historical data and simulation, large parts of past global change can be reconstructed, further broadening the scope of global change research and IA modelling (Bouwman et al., 2006; Costanza et al., 2007; Ellis et al., 2010). Examples include the RAINS/GAINS model (Amann et al., 2011) and its offshoots (Seebregts et al., 2001), the MESSAGE/MACRO-model (Messner and Schrattenholzer, 2000) and the IMAGE-TIMER-FAIR-model (Bouwman et al., 2006). A broader class of IAMs addresses the issue of climate change in relation to economic systems (Schneider and Lane, 2005; Weber et al., 2005). These typically involve coupling a rather simple macroeconomic model with a climate model, using greenhouse gas (GHG) emissions as the linking variable. The DICE model (Nordhaus, 1994) is an archetypical example, as are FUND (Tol, 1997) and PAGE (Hope, 2006). MERGE (Manne et al., 1995), IMACLIM-R (Sassi et al., 2010) and WITCH (Bosetti et al., 2009) are examples of more extensive macro-economic models including a detailed energy system.

One of the successful and widely applied methods to connect the natural science of global environmental change models to the complexities of societal processes is the scenario approach. The idea is to introduce qualitative storylines that support the model simulation with a plausible logic and appropriate parameter settings (de Vries, 2001, 2006). Models are then run several decades forward in order to construct scenarios, i.e. 'plausible and often simplified description[s] of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships' (Solomon et al., 2007). Scenarios can

[2] Many of the articles are based on developments following from two workshops funded by the GSD (Global System Dynamics and Policies) project of the Future & Emerging Technologies division of the European Commission, namely a workshop on "System Dynamic Models of Coupled Natural-Social Systems", in Bekkjarvik, Norway, 22–26 June 2009, (http://www.globalsystemdynamics.eu/index.php?id=eventssingleview&tx_ttnews), and a workshop on "Elementary Models for a Sustainable Economy" in Utrecht, The Netherlands, 21–24 January 2010 (de Vries, 2010; www.globalsystemdynamics.eu).

[3] See http://www.tias.uni-osnabrueck.de/integrated_assessment.php.