ARTICLE IN PRESS

Environmental Development xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Environmental Development

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

Nature-society system survivability model: Simulations of the principal natural and anthropogenic processes

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ARTICLE INFO

Keywords:
Modelling
Climate system
Nature society system
Survivability indicator
Sustainability classes
Solar–terrestrial coupling

ABSTRACT

The climate system is driven by internal and external forcings. Among the prime external forcings is the solar radiation, while the human activity is included among the principal intrinsic forcings. This means that basic components of nature and society are substantial parameters of the evolution of the climate system. Therefore, the consideration of the nature and society as a separate system, the nature-society system, will provide a new tool for the investigation of the climate system variability.

This paper is focused on the modelling of the evolution of the nature-society system, when considering a series of major natural and anthropogenic processes including several solar–terrestrial coupling mechanisms, biogeochemical cycles, physical processes operating in the terrestrial atmosphere, global climate change, global hydrologic balance and photosynthesis in ocean ecosystems. Among the main goals of this model is to estimate the survivability of the nature-society system under the conditions of limited energy resources. A series of simulation experiments are presented herein demonstrating the ability of the model to operate satisfactorily and reliably under various anthropogenic scenarios.

1. Introduction

The nature-society system (NSS) is closely linked to the climate system as the latter consists of the subsystems of the atmosphere, the hydrosphere, the lithosphere, the cryosphere and the biosphere (Nitu and Krapivin, 2014). The NSS survivability depends on its tendency to suppress large deviations in its structure and its components, returning to its equilibrium state. In other words, the NSS survivability indicates its ability to actively resist to external forcings, to maintain its features and to operate under certain conditions (Krapivin and Varotsos, 2007). Therefore, the evaluation of the NSS survivability under conditions of increasing instability stemming from anthropogenic processes is of great interest.

The traditional methods to build up simple global NSS models encounter some difficulties on the algorithmic description of many climatic (e.g. climate change due to variations in extra-terrestrial solar radiation), socio-economic and ecological processes, which lead to uncertainties (Alexandrov and Oikawa, 2002; Alexandrov et al., 2005; Efstathiou and Varotsos, 2010, 2012, 2013; Efstathiou et al., 2011; Lovejoy and Varotsos, 2016). These methods simply ignore such uncertainties and consequently the structure of the developed models does not adequately reflect the real processes. On the contrary, the global models of complex type use the evolutionary modelling method for the adaptation process related to the history of the components of the biosphere and global climate, thus overcoming the relative uncertainties (Nitu et al., 2000, 2004).

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http://dx.doi.org/10.1016/j.envdev.2017.07.003
Received 1 March 2017; Received in revised form 13 July 2017; Accepted 14 July 2017

Please cite this article as: Krapivin, V.F., Environmental Development (2017), http://dx.doi.org/10.1016/j.envdev.2017.07.003

To solve the afore-mentioned problem of the NSS survivability it is necessary to consider a trans-disciplinary approach taking into account the biogeochemical cycles, the global energy, the economic development, the human life conditions, the ecological restrictions, and the natural disasters, as well as, the feedbacks of nature on human activities (Dafelmair, 2002). However, numerous global environmental models of traditional type have limitations connected with their restricted structures that usually describe selected environmental processes that involve human-induced interventions only in the form of scenarios (Alexandrov and Oikawa, 2002; Alexandrov et al., 2005; Cracknell et al., 2009). The global NSS model supports such an approach and allows the investigation of various environmental situations that could occur. Furthermore, the proposed NSS model consists of sub-systems whose interactions change with time depending on several factors. It is evident that the perspective evolution of the NSS depends on the coordinated strategies of almost all countries and the availability of effective technology for global modelling and monitoring of critical environmental parameters.

An essential aspect of the above-mentioned issue is the proper definition of sustainable development. In this context, Krapivin and Varotsos (2007, 2008) consider the following four sustainability classes:

- *Nature*: 1) biodiversity, 2) global warming, 3) cycle of resources (land resources, solar energy etc), 4) water, soil, and air, 5) ecological formation.
- *Economy:* 1) energy (e.g. use of renewable (solar radiation, etc) or non-renewable energy sources), 2) resources productivity, 3) food, 4) financial status, 5) international cooperation.
- *Society:* 1) security, 2) mobility, 3) sex characteristics, 4) traditions and culture, 5) financial fluxes.
- *Well-being:* 1) satisfaction in life, 2) science and education, 3) participation in social life, 4) health, 5) differences in life standards.

The numerical modelling of the NSS evolution taking into account these classes, needs the investigation of universal indicators that could coordinate numerous characteristics of NSS. Such indicators, which assess the environmental characteristics, are the following:

- The Environmental Performance Index (EPI) that classifies the ability of the NSS items to describe the high-priority environmental issues (like global climate change) in policy areas, such as the protection of human health and ecosystems from environmental damages (Alpas et al., 2011; Angrick et al., 2014; Burgass et al., 2017).
- The Environmental Health Objective (EHO) that refers to the extent to which water quality deficiencies, air pollution, climate change and many other factors give rise to problems and reduce the quality of human life (Varotsos and Cartalis, 1991; Varotsos et al., 1995, 2007, 2014).
- The Ecosystem Vitality Objective (EVO) that measures the health of the NSS item's ecosystem by evaluating the state of agriculture, biodiversity and habitat, climate change, forestry, and fisheries (Olafsson et al., 2014).

This paper deals with an optimised version of the global NSS model that is based on the development of the survivability indicator and principal natural and anthropogenic processes, such as solar–terrestrial coupling mechanisms, physical processes operating in the terrestrial atmosphere, global climate change and photosynthesis in ocean ecosystems (Cracknell and Varotsos, 1994,1995; Varotsos, 1989, 1994, 2005, 2013; Varotsos et al., 1995, 2013). A set of simulation experiments covering several continents and individual countries are presented, providing also forecast of their development for the rest of the present century.

2. The NSS global model description

A conceptual diagram and block contents of the NSS global model (NSSGM) are presented in Fig. 1 and Table 1. As it is shown in Fig. 1 and is mentioned in Table 1, the NSSGM represents the NSS subsystems: soil-plant formations, World Ocean, climate, land water ecosystems, population, and mineral resources. Soil-plant formations play a significant role in the biogeochemical cycles and food production. World Ocean controls the exchange processes with the atmosphere and provides the food production. Land water ecosystems deliver the drinking water, provide the circulation of chemical elements, take part in biogeochemical cycles, and introduce the contributions to the food production. Human population is a dynamic subsystem. The main idea of the NSSGM is based on the concept of interactivity that developed by Krapivin and Varotsos (2007, 2008). This interactivity is appeared in the interactions between the NSS elements with their direct and indirect correlations. For example, natural disasters are considered as interactive components of global ecodynamics (Kondratyev et al., 2006). The model is constructed of blocks parameterizing natural and anthropogenic processes as well as the physical processes operating in various layers of the terrestrial atmosphere. Many blocks describe biogeochemical cycles of greenhouse gases; the global climate change, taking into account the solar–terrestrial coupling mechanisms (Kondratyev and Varotsos, 1995); the global hydrologic cycle in liquid, gaseous, and solid phases; productivity of soil-plant formations of numerous types; photosynthesis in ocean ecosystems, taking into account ocean depth and surface heterogeneity; demographic processes and anthropogenic changes (Lazaridou et al., 1985; Varotsos and Cracknell, 1993, 1994; Varotsos and Zellner, 2010; Varotsos et al., 1994). The blocks configuration points to the following types:

- Mathematical and physical models that describe specific processes in the NSS.
- Evolutionary or mixed type of blocks parameterizing processes in the NSS that are described only partly by mathematical or physical equations. In this case, the evolutionary modelling method is used for the parameterization of processes, when only experimental data exist.