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Global warming projections using the human–earth system model BNU-HESM1.0

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Abstract Future climate change is usually projected by coupled earth system models under specific emission scenarios designed by integrated assessment models (IAMs), and this offline approach means there is no interaction between the coupled earth system models and the IAMs. This paper introduces a new method to design possible future emission scenarios and corresponding climate change, in which a simple economic and climate damage component is added to the coupled earth system model of Beijing Normal University (BNU-ESM). With the growth of population and technological expertise and the declining emission-to-output ratio described in the Dynamic Integrated Climate-Economy model, the projected carbon emission is 13.7 Gt C, resulting in a 2.4 °C warming by the end of the twenty-first century (2080–2099) compared with 1980–1999. This paper also suggests the importance of the land and ocean carbon cycle in determining the CO_2 concentration in the atmosphere. It is hoped that in the near future the next generation of coupled earth system models that include both the natural system and the social dimension will be developed.

Keywords Coupled earth system model · Global change · Climate projection · Economic dimension

1 Introduction

Scientists, politicians and the public are all concerned about climate change. It is not just a single issue limited to the climate system, but rather a complex issue involving multiple disciplines including economics, energy, ecology, agriculture, health and security [1]. As well as climate attribution and simulation, future climate projection is of particular concern because it affects long-term climate mitigation and adaptation strategies. Generally, projections of climate change are obtained by driving coupled climate models with projections of anthropogenic greenhouse gas concentrations or emissions [2]. Thus a range of emission

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scenarios or pathways representing different future socio-economic, technology, or population patterns is devised, to provide the external forcing for coupled climate models. For example, the Intergovernmental Panel on Climate Change (IPCC) has released the well-known IS92 scenarios, the Special Report Emission Scenario (SRES), and the latest Representative Concentration Pathways (RCPs) for driving coupled climate models to develop corresponding climate scenarios [3].

Currently, the primary tools for devising emission scenarios are another type of climate model known as integrated assessment models (IAMs), which include parameters and variables to depict the chain of causes of climate change from energy, economics and climate policy, to emission and climate impacts [4, 5]. Widely used IAMs include the integrated model to assess the global environment (IMAGE) [6], the Asia-Pacific integrated model (AIM) [7], the global change assessment model (GCAM) [8], the Massachusetts Institute of Technology Integrated Global System Modeling framework (MIT-IGSM) [9] and the Model for Energy Supply Strategy Alternatives and their General Environmental impact (MESSAGE) [10].

However, it is clear that this systematic and proven climate projection approach consists of two independent processes, the emission scenario development and the climate projection. This leads to challenges and difficulties for mutual understanding and communication between developers of IAMs and coupled earth system models. For example, economic scientists or policymakers mainly focus on how the background of different emission scenarios are described in the IAMs, and this is also the focus of the IPCC working group III; while physical scientists pay more attention to the temperature, precipitation or sea ice changes projected by coupled climate models, and this is the focus of IPCC working group I. Obviously, except for the link of greenhouse gas concentrations or emissions, there are no other interactions between the IAMs and the coupled earth system models, even though the climate change would have impacts on the economic output. In addition, although most IAMs include modules describing the physical climate change processes, these are over-simplified compared with coupled earth system models. Specifically, these modules are unable to describe the complex land and ocean carbon cycle processes that play key roles in the natural system, and have no ability to describe changes of the cryosphere and other biological and physical processes [11].

So if we could add the IAMs (except for their climate change component) to the coupled earth system model, the new fully coupled models would not only produce the carbon emissions or concentrations and the background of population, GDP, and so on, but also calculate the corresponding future changes in the atmosphere, land, ocean, and ice. This would be a further advance for coupled earth system models in describing and understanding the complex interactions between human activities and natural systems. At the same time it would reduce the uncertainty in future emission projection caused by the simple climate model in the IAMs. Recently, some model development groups have tried to achieve this goal; for example, Collins et al. [12] and Bond-Lamberty et al. [13] developed the integrated Earth system model (iESM) by linking the community earth system model (CESM) to the global change assessment model (GCAM) [12, 13]. Yang et al. [14] developed the first version of the Beijing Normal University (BNU-HESM1.0) human–earth system model by combining the BNU-EMS and the Dynamic Integrated Climate-Economy (DICE) model [14, 15]. However, they only described the construction of the model and evaluated its ability to perform historical simulations, and did not use it for climate projection.

In this paper, we illustrate how the BNU-HESM1.0 may be used to project future carbon emission and climate change by calculating the possible future carbon emissions and climate change from 2006 to 2100. This paper is organized as follows. Brief descriptions of the BNU-HESM1.0 construction and experimental design are given in Sect. 2. The projection results follow in Sect. 3, and conclusions and further discussion are provided in Sect. 4.

2 Materials and methods

2.1 The BNU-HESM1.0 model

Briefly, the BNU-HESM1.0 includes two parts, the fully coupled earth system model BNU-ESM and an economics–emission model that forms part of the dynamic integrated climate-economy (DICE) model [15], and these two parts are connected by the climate damage function of DICE. The climate damage function represents the climate impacts on economic output; a 3 °C rise in global average temperature results in a 1.3 % loss of world output. The detailed description of the economic–emission module and climate damage function can be found in Nordhous [15].

The coupled earth system model BNU-ESM itself consists of four separate components simulating the atmosphere (CAM3.5), ocean (MOM4p1), land (CoLM) and sea ice (CICE4.1), and one coupler component (CPL6.0) connecting these four components. The Lund–Potsdam–Jena (LPJ) dynamic vegetation model (DVM) and the idealized ocean biogeochemical module (iBGC) are included in the CoLM and MOM4pl, respectively. The BNU-ESM is also one of the models that participated in the Coupled Model Intercomparison Project Phase 5 (CMIP5), and it is widely used in understanding climate change mechanisms and