

PREFACE

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# Preface for “Projection and impact assessment of global change”



Michio Kawamiya<sup>1\*</sup> , Masayoshi Ishii<sup>2,3</sup>, Nobuhito Mori<sup>4</sup>, Eiichi Nakakita<sup>4</sup>, Izuru Takayabu<sup>2,3</sup> and Masahiro Watanabe<sup>5</sup>

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Scientists are now more confident than ever that climate is changing due to greenhouse gas emissions from human activities, and that the impacts of the altered environment on society have already become apparent. Numerical simulations based on the Coupled Model Intercomparison Project Phase 6 (CMIP6) protocol, a design for climate change projection with numerical models for global environment (Eyring et al. 2016), are being conducted by leading climate modeling centers worldwide, and the product data are being distributed internationally. The Ministry of Education, Culture, Sports, Science and Technology (MEXT) launched the TOUGOU program in FY 2017 to develop numerical models to generate the CMIP6 projection data and utilize them to dynamical downscaling and impact assessment research (Fig. 1). This special issue consists mainly of the studies conducted under the TOUGOU program and also contains research papers related to the program. We hope that this special issue contributes to grasping the progress made by the TOUGOU program in the field of climate change projection research.

Oshima et al. (2020) measure the current radiative forcing in their model developed for CMIP6 and point out the need for further research on the interaction between aerosols and ice clouds. Such climate models are increasingly being used not only to make projections but also to assess the contribution of human-induced environmental change on the extreme events under the present climate—the approach called the event attribution.

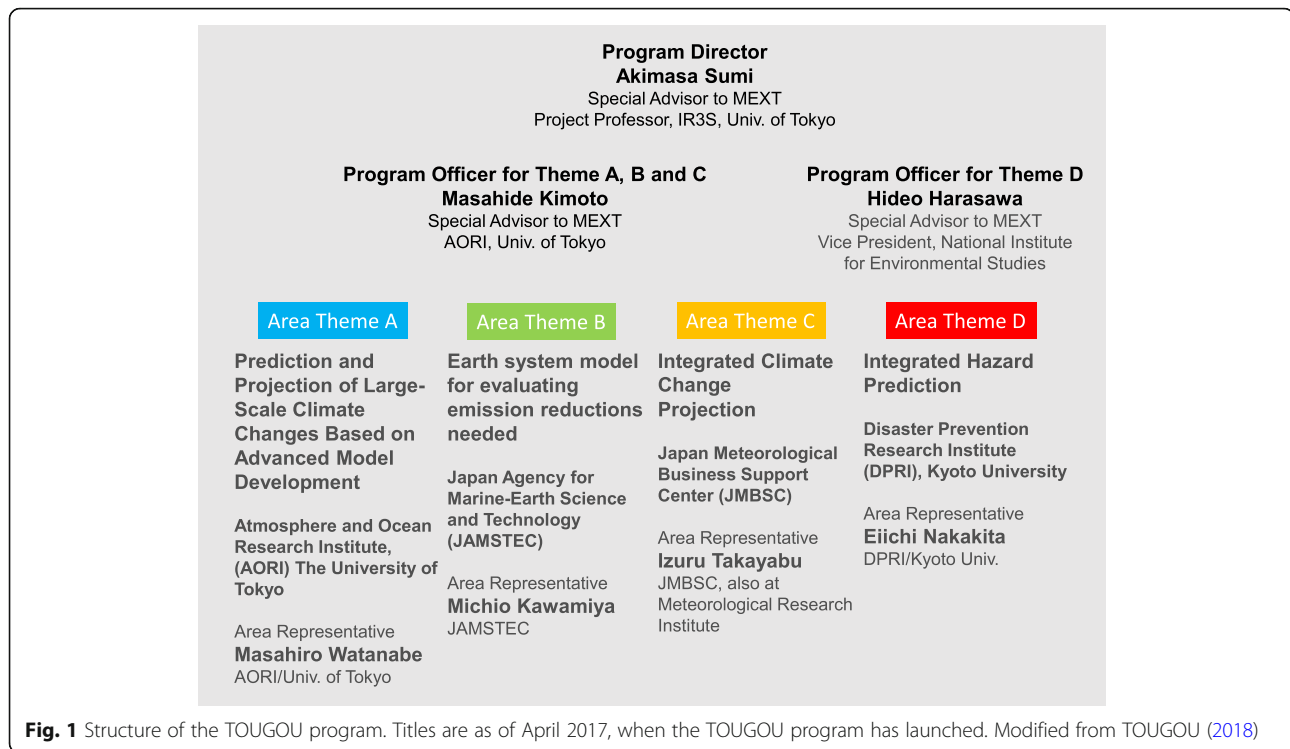
For this approach, Hasegawa et al. (2020) introduce a new method in which an atmosphere-ocean coupled model is deployed instead of an atmosphere-only one.

Projection data generated by global climate models such as the CMIP6 models can be applied, e.g., to evaluate the global geographic distribution of terrestrial precipitation change with uncertainty, as in the work of Ito et al. (2020b), and to elucidate the processes of sea level change associated with heat absorption and transport in the North Pacific Ocean, as presented by Suzuki and Tatebe (2020). Wang and Zhang (2020) utilize projection data to estimate future changes in wetness over Asia, which has a sub-continental spatial scale so that even relatively low-resolution data can be used as is. On the other hand, when focusing on local scale climate (e.g., a specific country size) to conduct an assessment to underpin adaptation measures, it is often necessary to apply a downscaling scheme to enhance the resolution of the projection data, as Yamamoto et al. (2021) do with a regional dynamical model when they assess the impact of climate change on flood inundation in Indonesia. A global model with very high resolution can also be used, as in the Mekong River flood projection by Try et al. (2020).

When assessing risks based on future projections, it is crucial to ensure a sufficient number of ensemble members and improve statistical reliability. The projection dataset “Database for Policy Decision Making for Future Climate Change” (d4PDF, Mizuta et al. 2017) has been developed with this in mind. It includes subsets for 4 °C, 2 °C, and 1.5 °C temperature increases compared to pre-industrial levels, as introduced by Nosaka et al. (2020),

\* Correspondence: [kawamiya@jamstec.go.jp](mailto:kawamiya@jamstec.go.jp)

<sup>1</sup>Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan  
Full list of author information is available at the end of the article



who examine the scalability of temperature and precipitation changes among these subsets. Many impact assessment studies have utilized d4PDF, such as the one on snowfall for mountain areas under a warmed climate by Kawase et al. (2020). An extensive review on studies using d4PDF was provided by Ishii and Mori (2020).

The alternations due to climate change in extreme events such as typhoons are of great interest to society. Nayak and Takemi (2020) have analyzed selected historical extreme events having in mind the expected northward shifts of affected areas in the future, and discuss the relationship between typhoon locations and extreme precipitations in northern Japan. Yamada et al. (2021) present a study focusing on the survival rate of typhoon “seeds” until they develop into typhoons using global data from High-ResMIP (Haarsma et al. 2016), a collection of relatively high-resolution models among the CMIP6 models. Takemi and Ito (2020), on the other hand, perform a case study using a regional model and show that in complex terrain, improvements could be expected with higher resolutions down to the level of several hundred meters.

High-resolution oceanographic data are essential for elucidating the impacts on fisheries and changes in storm surge intensities. Nishikawa et al. (2021) describe a model setup for creating an ocean projection dataset with a resolution of up to 2 km in the seas around Japan and validate the output data. Based on the so-obtained dataset named “Future Ocean Regional Projection” (FORP), Nishikawa et al. (2020) evaluate the frontal shift

of the Kuroshio and Oyashio under the warm climate, with a suggestion of an appropriate definition of fronts.

The Global Stocktake (GST) under the United Nations Framework Convention on Climate Change (UNFCCC), due for the first time in 2023, will discuss whether the emission reduction goals of each participating country are consistent with the climate change mitigation targets of 2 °C or 1.5 °C, including possible enhancements of the current reduction goals (UNFCCC 2015). Earth system models (ESMs), climate models with the carbon cycle, and other biogeochemical processes as reviewed by Kawamiya et al. (2020), play an essential role in yielding scientific knowledge as inputs to such an arena. Hajima et al. (2020) analyze the instantaneous CO<sub>2</sub> doubling experiment using two versions of an ESM and obtain some enlightening results, including visualization of the differences in heat and carbon uptake processes by the ocean. The differences in heat and carbon behavior are relevant to determining a quantity called transient climate response to emission (TCRE), the proportionality of the relationship between carbon emissions and temperature rise (IPCC 2018). TCRE is the key to calculating the cumulative anthropogenic emission compatible with meeting the mitigation targets. The dependence of TCRE on emission scenarios, as shown by Tachiiri (2020), is also a factor that should be considered when constructing emission reduction scenarios.

Taking advantage of the characteristics of ESM to deal with forest dynamics, Ito and Hajima (2020) have shown

that land use change due to human activities has a considerable impact on the runoff of soil moisture to rivers and vegetation biomass. Land use change deserves attention as a process that excites the interaction between human society and climate change. Tachiiri et al. (2021) surveyed the media that can form a feedback loop between the socio-economy and the global environment, citing the temperature dependence of labor productivity in addition to land use change.

While ESMs have the benefit of incorporating various biogeochemical processes and representing their interactions with climate change, many processes have been identified as desirable but have not yet been implemented in most ESMs. An example is the dynamics of permafrost, for which Saito et al. (2020) use a newly developed model to determine the distribution of soil carbon and ground ice under the present climate. Yokohata et al. (2020b) have shown that improved modeling of physical properties of soil in polar regions can significantly modify future permafrost area projections. Furthermore, Yokohata et al. (2020a) assess greenhouse gas emissions from permafrost by combining the distributions obtained by Saito et al. (2020) with the projection by Yokohata et al. (2020b).

Other major processes lacking in current ESMs include the various transport processes that link the ocean and land material cycles. Ito et al. (2020a) present improved modeling and results of iron supply to the ocean via aerosols generated by forest fires. Hatono and Yoshimura (2020) introduce a sediment dynamics model that can reproduce the transport of suspended sediment from land to the ocean through rivers. Their model has been implemented in the Integrated Land Simulator (ILS) framework described by Nitta et al. (2020), which accommodates component models of land surface processes developed mainly in Japan. ILS is expected to be introduced into several ESMs in the future.

Models that simulate the global environment are increasingly embedding processes functioning on the real planet. This special issue will provide a glimpse into the evolution of the tool that is becoming indispensable to humanity's stewardship of the changing global environment.

#### Abbreviations

CMIP6: Coupled model intercomparison project phase 6; d4PDF: Database for policy decision making for future climate change; ESMs: Earth system models; FORP: Future ocean regional projection; GST: Global stocktake; ILS: Integrated land simulator; HighResMIP: High resolution model intercomparison project; MEXT: Ministry of education, culture, sports, science and technology; TCRE: Transient climate response to emission; TOUGOU: Integrated research program for advancing climate models (the abbreviation is from the Japanese word for "integration"); UNFCCC: United Nations framework convention on climate change

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#### Authors' contributions

MK leads theme B of the TOUGOU program and composed the main text. MW, IT, and EN are the leaders of themes A, C, and D respectively and examined the corresponding parts of the text. MI and NM manage and promote researches of themes C and D, respectively, and checked the text regarding the papers from the themes they are responsible for. All authors read and approved the final manuscript.

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#### Declarations

##### Competing interests

The authors declare that they have no competing interests.

##### Author details

- <sup>1</sup>Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan.
- <sup>2</sup>Meteorological Research Institute, Japan Meteorological Agency, Tsukuba, Japan.
- <sup>3</sup>Japan Meteorological Business Support Center, Tokyo, Japan.
- <sup>4</sup>Disaster Prevention Research Institute, Kyoto University, Uji, Japan.
- <sup>5</sup>Atmosphere and Ocean Research Institute, University of Tokyo, Kashiwa, Japan.

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