Area Theme A — Prediction and Projection of Large-Scale Climate Changes Based on Advanced Model Development

Area Representative : **Masahiro Watanabe** (Professor, Atmosphere and Ocean Research Institute, The University of Tokyo)

Subject		Representative
(i) Improving climate models that can contribute to more reliable global environmental predictions		
a	Near-future climate change predictions and promotion of CMIP6 experiments	Hiroaki Tatebe Japan Agency for Marine-Earth Science and Technology, Unit Leader
b	Development of climate models with sophisticated physical processes	Kentaro Suzuki Atmosphere and Ocean Research Institute, The University of Tokyo, Associate Professor
c	Greater sophistication of land surface models	Yukiko Hirabayashi Institute of Industrial Science, The University of Tokyo, Associate Professor
(ii) Reducing the uncertainty of climate change predictions and increasing the depth of scientific knowledge		
a	Understanding and reducing uncertainty of climate sensitivity	Tomoo Ogura National Institute for Environmental Studies, Senior Researcher
b	Analysis of factors in past climate changes and unusual weather and future predictions	Masahiro Watanabe Atmosphere and Ocean Research Institute, The University of Tokyo, Professor
c	Understanding of cloud-precipitation-circulation process using global non-hydrostatics model	Akira Noda Japan Agency for Marine-Earth Science and Technology, Unit Leader

Area Theme B — Sophisticated Earth system model for evaluating emission reductions needed

Area Representative : **Michio Kawamiya** (Director, Project Team for Advanced Climate Modeling, Japan Agency for Marine-Earth Science and Technology)

Subject		Representative
(i) Development of ESM and analysis of the Earth system		
a	Development and application of ESM	Tomohiro Hajima Japan Agency for Marine-Earth Science and Technology, Deputy Research Unit Leader
b	Stochastic assessment of temperature rise via multi-model analysis	Junichi Tsutsui Central Research Institute of Electric Power Industry, Duputy Associate Vice President
c	Organization of ESM development environment	Takashi Arakawa Research Organization for Information Science and Technology, Senior Researcher
(ii) Earth-human system interaction		
a	Earth - Socioeconomic System interaction	Kaoru Tachiiri Japan Agency for Marine-Earth Science and Technology, Unit Leader
b	Earth System - water resource/crop/land utilization model linkage	Tokuta Yokohata National Institute for Environmental Studies, Senior Researcher
(iii) Technical and clerical support for inter-theme cooperation		Michio Kawamiya Japan Agency for Marine-Earth Science and Technology, Director

Area Theme C — Integrated Climate Change Projection

Area Representative : **Izuru Takayabu** (Japan Meteorological Business Support Center)

Subject		Representative
(i) Development of high-precision models integrated with climate-relevant processes		Masayoshi Ishii Japan Meteorological Business Support Center
(ii) Development of climate scenarios for multi-stakeholder applications and understanding the mechanisms of climate change		
a	Development of climate scenarios for multi-stakeholder applications and understanding the mechanisms of future changes in extreme events	Toshiyuki Nakaegawa Japan Meteorological Business Support Center
b	High-resolution simulation of typhoons and extreme events	Tsuboki Kazuhisa Institute for Space-Earth Environmental Research, Nagoya University, Professor
(iii) Advancing international collaboration through the application of a high-performing climate model over many countries in the Asia-Pacific region		Hidetaka Sasaki Japan Meteorological Business Support Center

Area Theme D — Integrated Hazard Prediction

Area Representative : **Eiichi Nakakita** (Professor, Disaster Prevention Research Institute, Kyoto University)

Subject	Representative
(i) Long-term assessment of intensity and frequency of extreme hazards	Nobuhito Mori Disaster Prevention Research Institute, Kyoto University, Associate Professor
(ii) Seamless hazard prediction until the end of the 21st century	Kenji Tanaka Disaster Prevention Research Institute, Kyoto University, Associate Professor
(iii) Hazard analysis of past disasters and assessment of climate change factors	Tetsuya Takemi Disaster Prevention Research Institute, Kyoto University, Associate Professor
(iv) Hazard assessment in Asian and Pacific countries and international cooperation	Yasuto Tachikawa Graduate School of Engineering, Kyoto University, Professor
(v) No-regret adaptation strategies with consideration for various changes	Hirokazu Tatano Disaster Prevention Research Institute, Kyoto University, Professor
(vi) Development of bias correction methods and extreme values assessment technology	Toshikazu Kitano Department of Civil Engineering, Nagoya Institute of Technology, Professor

MEXT MINISTRY OF EDUCATION, CULTURE, SPORTS, SCIENCE AND TECHNOLOGY-JAPAN

Ministry of Education, Culture, Sports, Science and Technology-Japan
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TOUGOU | Integrated Research Program for Advancing Climate Models

Japan Agency for Marine-Earth Science and Technology
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Integrated Research Program for Advancing Climate Models

MEXT MINISTRY OF EDUCATION, CULTURE, SPORTS, SCIENCE AND TECHNOLOGY-JAPAN

About the Study Program for Greater Sophistication of Integrated Climate Model

In recent years the international community has achieved significant developments with respect to climate change measures. In December 2015, the 21st session of the Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change was held and the Paris Agreement, which then came into force on 4 November 2016, was adopted and with the aims of keeping the average global temperature rise below 2 degrees Celsius above pre-industrial levels, while also the pursuit of limiting the temperature increase to 1.5 degrees Celsius at the same time, and strengthening the ability of countries to deal with the impact of any climate change. The Sustainable Development Goals (SDGs), which were adopted in September 2015 at the United Nations Sustainable Development Summit, stipulates climate change measures to be one of 17 goals that need to be achieved by 2030. In addition, the Intergovernmental Panel on Climate Change (IPCC), which assesses the most recent scientific information, has commenced upon the preparation of the Sixth Assessment Report.

Meanwhile, climate change measures are also being developed in Japan as well. The Japanese government approved a "National Plan for Adaptation to the Impact of Climate Change" in a Cabinet meeting held in November 2015 in thereby minimizing or avoiding the impact of climate change and establishing a sustainable society. In response to these types of increased interest in the need for climate change measures both at home and abroad studying climate change predictions, which utilize state-of-the-art science and technology, is essential in both foreseeing the future and developing effective measures. In addition, it is politically important to Japan to improve its presence in climate-change diplomacy and to consistently contribute to domestic climate change measures via use of those technologies.

With the aims of further advancing climate change studies and then utilizing the results for the good of society the Ministry intends to create an integrated study system with four cooperative study area themes via expansive use of the results of the Program for Risk Information on Climate Change (2012-2016), address the need for greater elucidation of climate change mechanisms, increase the sophistication of climate change prediction models and assessment of the impact of climate change, and challenge ourselves to develop sophisticated climate change prediction data sets.

PD

Akimasa Sumi

Special Advisor to MEXT
Project Professor, Integrated Research System for Sustainability Science, The University of Tokyo

PO Theme A, B and C

Masahide Kimoto

Special Advisor to MEXT
Vice Director and Professor, Atmosphere and Ocean Research Institute, The University of Tokyo

PO Theme D

Hideo Harasawa

Special Advisor to MEXT
Vice President, National Institute for Environmental Studies

As the head of the project the **PD (Program Director)** manages the program in the most efficient and effective manner while also being responsible for the overall coordination of the program. A **PO (Program Officer)** will be assigned to each area theme as assistance to the roles of the PD (progress management of the study subjects, coordination of study plans, etc.).

Message from Program Director

Background and Objectives of Integrated Program

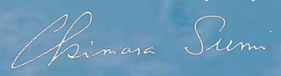
Heavy rainfall of over 50mm of hourly precipitation, for example the heavy rainfall in the Northern Kyushu region in July 2017, has been observed in various areas throughout Japan. The prediction of the climate model that, "As global warming progresses, heavy rainfall will increase" , seems to becoming a reality. As stated in the Sustainable Development Goals（SDGs）adopted at the United Nations Conference held in 2015 we now need to address the global warming issue together with other goals in a comprehensive manner rather than independently. In a similar fashion in Japan the authorities concerned will need to closely cooperate with each other in promoting the necessary measures to take with regard to adapting to climate changes. Addressing the impact of uncertain climate changes in the appropriate manner therefore makes improving scientific knowledge on global warming essential.

Understanding and predicting climate change using climate models is an important field that can provide valuable scientific knowledge on global warming. While developing the Earth Simulator, which had a positive global impression, Japan has been constantly improving our understanding of climate change and enabling more sophisticated global arming predictions through use of that simulator. This movement then led to the launch of the Study Program for Sophistication of Integrated Climate Model in 2017 for a planned period of five years and with the aim of further development of climate models.

Development of the Earth Simulator resulted in a remarkable increase in our scientific knowledge on global warming predictions. Natural fluctuations are an essential factor in climate change. A new method of calculating the impact of global warming on climate change was developed and the means of addressing physical mechanisms that affect the climate, for example clouds, significantly improved. For example, a climate model that represents clouds graphically is now being utilized in various ways such as assessing the impact on industry and the ecosystem.

This program aims to further develop climate models and to reflect the knowledge gained through them in the adaptation plans of actual regions in coordination with socioeconomic scenarios. A sincere effort to respond to the questions that society needs answers for in this process will open the door to a new type of science. We appreciate your continued support and encouragement.

PD(Program Director)
Akimasa Sumi
Special Advisor to MEXT
Project Professor, Integrated Research System for Sustainability Science, The University of Tokyo



Area Theme A — Prediction and Projection of Large-Scale Climate Changes Based on Advanced Model Development

Atmosphere and Ocean Research Institute, The University of Tokyo

▶Area Representative
Masahiro Watanabe
(Professor, Atmosphere and Ocean Research Institute, The University of Tokyo)

Area subjects

- Improving climate models that can contribute to more reliable global environmental predictions
- Reducing the uncertainty of climate change predictions and increasing the depth of scientific knowledge

▶Participating organizations
Japan Agency for Marine-Earth Science and Technology, National Institute for Environmental Studies

Area Theme B — Sophisticated Earth system model for evaluating emission reductions needed

Japan Agency for Marine-Earth Science and Technology

▶Area Representative
Michio Kawamiya
(Director, Project Team for Advanced Climate Modeling, Japan Agency for Marine-Earth Science and Technology)

Area subjects

- Development of ESM and analysis of the Earth system
- Earth-human system interaction
- Technical and clerical support for inter-theme cooperation

▶Participating organizations
Central Research Institute of Electric Power Industry, Research Organization for Information Science and Technology, National Institute for Environmental Studies

Area Theme C — Integrated Climate Change Projection

Japan Meteorological Business Support Center

▶Area Representative
Izuru Takayabu
(Japan Meteorological Business Support Center)

Area subjects

- Development of high-precision models integrated with climate-relevant processes
- Development of climate scenarios for multi-stakeholder applications and understanding the mechanisms of climate change
- Advancing international collaboration through the application of a high-performing climate model over many countries in the Asia-Pacific region

▶Participating organizations
Nagoya University

Area Theme D — Integrated Hazard Prediction

Disaster Prevention Research Institute, Kyoto University

▶Area Representative
Eiichi Nakakita
(Professor, Disaster Prevention Research Institute, Kyoto University)

Area subjects

- Long-term assessment of intensity and frequency of extreme hazards
- Seamless hazard prediction until the end of the 21st century
- Hazard analysis of past disasters and assessment of climate change factors
- Hazard assessment in Asian and Pacific countries and international cooperation
- No-regret adaptation strategies with consideration for various changes
- Development of bias correction methods and extreme values assessment technology

▶Participating organizations
Nagoya Institute of Technology, Hokkaido University, National Agriculture and Food Research Organization, Public Works Research Institute

Theme A Prediction and Projection of Large-Scale Climate Changes Based on Advanced Model Development

Society-relevant climate change studies based upon advanced climate modeling for use in future predictions

▶Area Representative : Masahiro Watanabe
(Professor, Atmosphere and Ocean Research Institute, The University of Tokyo)

In 2015, the historic Paris Agreement concerning retaining the global temperature increase at below 2°C and hopefully below 1.5°C was concluded at COP21, which will accelerate national actions being taken toward further adaptation to and mitigation of global warming. The basis for the aforementioned actions is the huge amount of output from climate change simulations regarding the future path of greenhouse gases, with data having so far been provided by the Coupled Model Intercomparison Project (CMIP) in which world' s climate modeling centers have cooperated in using Global Climate Models (GCMs).

Theme A of the TOUGOU program concerns active involvement in the latest phase 6 of CMIP (CMIP6) using the Earth Simulator and a GCM called MIROC6 that was developed in a previous MEXT program. In addition to historical scenario simulations of 20th and 21st century climate changes a large amount of data will be produced through a number of different types of GCM simulations, and which can then be used to identify scientific priority issues that include near-term climate change predictions, regional sea-level changes, changes in climate extremes, and uncertainty with the Earth' s climate sensitivity. These studies will be used in the aim of contributing to the IPCC 6th Assessment Report (AR6) that will be published in 2021.

Societal concerns about the increasing extreme weather events have been increasing. During previous years 'Event Attribution' studies have been carried out with the aim of providing answers to scientific questions relevant to societal concerns, and including the risk of extreme temperature events due to human-induced climate changes over the recent decade as well as near future. This research activity will be expanded upon via Theme A in thereby enhancing society-relevant global warming studies.

Two fundamental technological infrastructures are crucial in achieving the relevant results: a fast supercomputer (namely, Earth Simulator) and GCMs that better reproduce the real climate system. Further development of GCMs with more focus on improving physical processes such as clouds is mandatory, as well as upgrading the data assimilation system for use in near-term climate predictions.

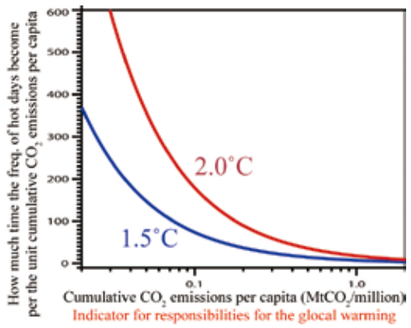


Fig. 1: Inequalities with increasing extreme hot events per unit responsibility and capability of mitigation
Relationships between "the cumulative CO_2 emissions per capita" and "how long the frequency of extreme hot days (1 day per 100 years with the present climate) become per the unit cumulative CO_2 emissions per capita" with respect to 1.5ºC and 2.0ºC runs. There is a significant inequality with the 2.0ºC runs; regions with lower responsibilities have larger increases in hot days per unit responsibility.

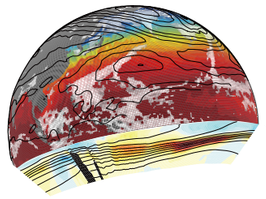


Fig. 2: Climate model MIROC6
Global climate system model is an essential tool for providing reliable projections of future climate, and advancing the climate modeling technique is one of important issues in the Theme A.

▶Participant organizations JAMSTEC, NIES

Theme B Sophisticated Earth system model for evaluating emission reductions needed

Sophisticated Earth system model for evaluating emission reductions needed

▶Area Representative : Michio Kawamiya
(Director, Project Team for Advanced Climate Modeling, Japan Agency for Marine-Earth Science and Technology)

The IPCC's Fifth Assessment Report (2013) revealed the temperature rise due to global warming to be in good proportion with the cumulative emission of anthropogenic carbon dioxide. This relationship can be used to estimate total acceptable emissions if society is to achieve the 2°C target. About two thirds have already been emitted of total emissions thus estimated. This leads to the understanding that achieving the 2°C target or the 1.5°C target mentioned in the Paris Agreement will not be easy at all, however, the uncertainty involved in the estimate is also quite large. The exact value of the estimate can lead to huge differences in the cost of global change mitigation and thus drastic changes in what future society will be like in terms of energy production and consumption.

The "Earth System Model" (ESM), a climate model that utilizes biological and chemical processes, is used in computing total overall acceptable emissions and examining all the associated uncertainties. Theme B involves further development of ESM via the introduction of the new biogeochemical processes that are needed in more sophisticated global change projections, for example nitrogen and methane cycling, improving the physical processes involved with the atmosphere and oceans in thereby enabling the performance of more elaborate evaluations, and taking into account the interaction between human activities and the Earth system. We will also work on simulation studies for use in evaluating the effectiveness of artificial control of the climate such as scattering sunlight by distributing fine particles throughout the atmosphere in order to slow down the global change. In addition, keeping an eye on abrupt changes in the Earth system, for example the collapse of the Antarctic ice sheets, with which the probability may be low but the damage gigantic, will be necessary.

Through these activities Theme B aims to contribute to international efforts to establish a pathway to mitigating global change, including the Climate Change Framework Convention, which entered a new phase with the Paris Agreement.

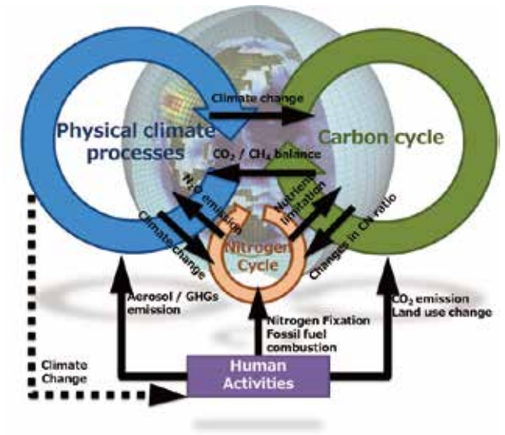


Fig. 1: Conceptual diagram of global change projection via an Earth System Model that incorporates nitrogen circulation
Anthropogenic emissions of greenhouse gasses and artificial nitrogen fixation (process wherein nitrogen in the atmosphere is transformed into a biologically reactive form) are increasing, and are critical factors with future global environment projections. Comprehensive projections that take into consideration the interactions between the carbon and nitrogen cycles and the physical climate change are very important.

▶Participant organizations CRIEPI, NIES, RIST

Theme C Integrated Climate Change Projection

Elucidating how and why regional warming occurs so that global warming information can be utilized by society.

▶Area Representative : Izuru Takayabu
(Japan Meteorological Business Support Center)

International society is seeking stronger cooperation with “the physical science basis” of Working Group I (WGI) and “Impacts, adaptation and vulnerability” of Working Group II (WGII) within the Intergovernmental Panel on Climate Change (IPCC). In Japan, the development of global warming adaptation measures for all the local government units and various types of information on warming projections for use in those measures are being sought.

Among warming projections the change in the probability of extreme weather, for example typhoons and heavy rainfall during the rainy season, has recently drawn a lot of attention. High-resolution and precise global and regional climate models will be used in this theme and with the aim of elucidating how and why extreme weather changes that can have such a major impact on regional climates occur. The data from warming projection calculations can then be used to examine the types of impact they will have on society. Data that meets all of the types of demand for it therefore needs to be output.

We intend to carry out future projections and experiments for use in reproducing current climates in various scenarios and experiments that reproduce past climates through assimilating data. Then by assessing the adequacy of the resulting data we can provide the various users of it with guidelines for them to use in making the decision on which data they can best use. In addition, the intention is to develop a new and high-resolution downscaling model system to ensure that the data can then be utilized in a greater variety of fields and in warming impact assessment of environmental contamination, and in agriculture and renewable energy etc. The studies will be used in coordinated studies that include staff exchanges with other countries that are vulnerable to global warming (e.g. Southeast Asian countries) as well as in domestic coordinated studies. In this way the studies can then contribute to warming projections for use at actual sites and studies on their utilization.

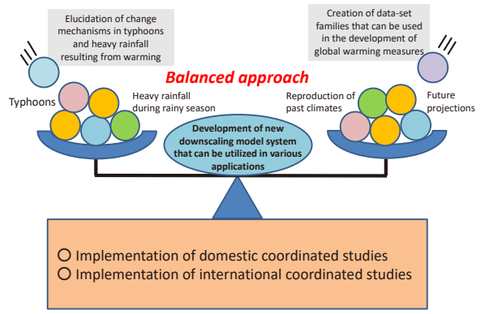


Fig. 1: Overview of Integrated Climate Change Projection
The figure shows the overall relationship between the subjects. The global warming projection study involves two important points: 1) elucidation of change mechanisms and 2) creation of available data sets. We intend to study both those points in a well-balanced manner. In addition to reproducing and predicting climate change we will develop a model system that can be flexibly used in various applications. The results will then be utilized in coordinated studies with other countries that are vulnerable to global warming such as Southeast Asian countries as well as in domestic study projects including the integrated program Area Theme D.

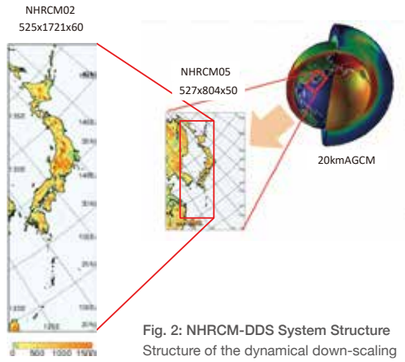


Fig. 2: NHRCM-DDS System Structure
Structure of the dynamical down-scaling system is shown here. The most inner model is 2km grid, cloud resolving model which includes urban canopy sub-model.

▶Participant organizations **Nagoya University**

Theme D Integrated Hazard Prediction

Projecting the impact of global warming on disasters and elucidating the trend in future with no-regret adaptation strategies.

▶Area Representative : Eiichi Nakakita
(Professor, Disaster Prevention Research Institute, Kyoto University)

How will global warming affect typhoons, floods, sediment disasters, and river flows? Theme D aims to project how devastating these disasters will change over the next 100 years and scientifically reveals the relationship between global warming and disasters. Mainly the following two analysis methods will be adopted: the first one is to quantify the probability of climate change impact on typhoons and flooding etc. and the second one is to assess the impact of climate change with the worst case scenarios that consider extraordinary situations such as super typhoons. In recent years, Japan as well as other countries have been affected by frequent and unprecedented disasters. Potential damages by such record-breaking disasters enhanced by climate change should be assessed from scientific and engineering perspectives. Moreover, we hope to provide basic information on appropriate measures needed in the future by understanding also the economic impacts.

By conducting integrated hazards assessment, Theme D will analyze future changes of hazards and their social impacts in order to provide essential information and the necessary methods for use in preparing no-regret adaptation measures. We therefore intend to take into account what we need to consider and prepare for use in no-regret and proactive adaptation strategies by increasing the sophistication, integration, and depth of hazard models. In addition, we will establish the foundation for the necessary adaptation in other Asian countries as well as in Japan. We have been working on “the future changes of design external forces and the estimation of largest-class external forces” through KAKUSHIN, SOUSEI and this TOUGOU program up until now, which will be used to proceed with “the impact assessment on meteorological disasters, water-related disasters, coast disasters and risks” from a new and integrated point of view.

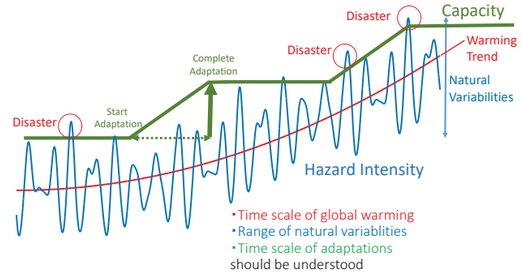


Fig. 1: Seamless impact assessment and adaptation strategies
Utilizing the 100-year seamless experiment etc. produced by Theme C, we will assess various impacts (e.g. floods, storm surges, water resources and cycles) considering continuous climate changes from now until the end of 21st century to propose climate change adaptations (e.g. in agriculture and coastal zones).

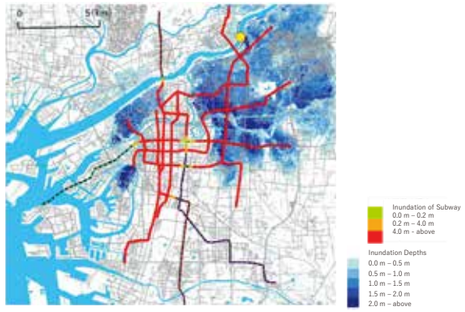


Fig. 2: An example of large scale flood inundation simulation for the downstream of the Yodo River basin (Osaka City)
Figure shows an example of large scale flood inundation simulation in the downstream of the Yodo River basin (Osaka City). It shows the spreading of flooded water on the ground as well as flooding along the subway system.

▶Participant organizations **Nagoya Institute of Technology, Hokkaido University, National Agriculture and Food Research Organization, Public Works Research Institute**