List of Research Subjects

Theme A Prediction and diagnosis of imminent global climate change

Representative: Masahide Kimoto
Vice Director/Professor, AORI, the University of Tokyo

Research Subject		Sub-Research Subject	Institutes & Representatives	
(i) Understanding mechanisms of climate variability and change	a	Studies on prediction and predictability of climate variability from interannual to decadal time scales	AORI, the Univ. of Tokyo Associate Professor	Masahiro Watanabe
	b-1	Towards reducing uncertainty in model-based estimation of climate sensitivity	NIES Senior Researcher	Tomoo Ogura
	b-2	Reduction of uncertainty in climate models relevant to climate sensitivity	JAMSTEC Senior Scientist	Masaki Sato
(ii) Development of an integrated prediction system for global climate studies	a	Development of a seamless prediction system for seasonal-to-decadal time scales	Meteorological Research Institute Senior Researcher	Masayoshi Ishii
	b	Development of data assimilation technology for optimizing initial and boundary conditions	JAMSTEC Research Unit Leader	Hiroaki Tatebe

Theme B Climate change projection contributing to stabilization target setting

Representative: Michio Kawamiya
Director, Project Team for Risk Information on Climate Change, Strategic Research and Development Area, JAMSTEC

Research Subject		Sub-Research Subject	Institutes & Representatives	
(i) Long-term global change projection based on diverse scenarios	a	Development of an earth system model dealing with variations of greenhouse gasses,land use change, etc.	JAMSTEC Research Unit Leader	Shingo Watanabe
	b-1	Information gathering and examination on socio-economic scenarios toward stabilization target setting	JAMSTEC Deputy Research Unit Leader	Kaoru Tachiiri
	b-2	Integrated assessment on climate projection experiments and socio-economic scenarios	CRIEPI, Environmental Science Research Laboratory Deputy Associate Vice President	Jyunichi Tsutsui
(ii) Obtaining scientific perceptions on large-scale variations and modifications of climate	a	Development of technologies for numerical investigations on tipping elements andirreversibility of environmental changes (ice sheet collapse, etc.)	JAMSTEC Director	Michio Kawamiya
	b	Development of technologies for numerical investigations on geoengineering (stratospheric aerosol injection, etc.)	JAMSTEC Director	Michio Kawamiya

Theme C Development of basic technology for risk information on climate change

Represenrative: Izuru Takayabu
Director, Atmosperic Environment and Applied Meteorology Research Department, Meteorological Research Institute

Research Subject		Sub-Research Subject	Institutes & Representatives	
(i) Probabilistic climate projection for risk assessment	a	Efficient approach for climate ensemble experiment	NIED Senior Researcher	Koji Dairaku
	b	Development of statistical methodology of ensemble data on climate change	ISM Associate Professor	Genta Ueno
	c	Improvement in cost-efficiency of dynamical downscaling for ensemble data	IIS, the Univ. of Tokyo Associate Professor	Kei Yoshimura
(ii) Producing a standard climate scenario by using super high resolution models	a	Development of quantification method for reliability and uncertainty of climate change information	Tsukuba Univ. Professor	Hiroaki Ueda
	b	Downscaling of the change in future weather extremes by using high-resolution models	Meteorological Research Institute Director	Izuru Takayabu
	c	Development of a coupled ocean-atmosphere non-hydrostatic model for typhoon research	ISEE CIDAS, Nagoya Univ. Professor	Kazuhisa Tsuboki

Theme D Precise impact assessments on climate change

Represenrative: Eiichi Nakakita
Vice Director/Professor, DPRI, Kyoto University

Research Subject		Sub-Research Subject	Institutes & Representatives	
(i) Climate change impacts on natural hazards	a	Risk assessment of meteorological disasters under climate change	DPRI, Kyoto Univ. Associate Professor	Tetsuya Takemi
	b	Risk assessment of water-related disasters under climate change	Kyoto Univ. Professor	Yasuto Tachikawa
	c	Risk assessment of coastal disasters under climate change	DPRI, Kyoto Univ. Associate Professor	Nobuhito Mori
	d	Measuring socio-economic impacts of climate change and effectiveness of adaptation strategies	DPRI, Kyoto Univ. Professor	Hirokazu Tatano
	e	Development of risk assessment and adaptation strategies for water-related disaster in Asia	ICHARM Deputy Director	Katsuhito Miyake
(ii) Climate change impacts on water resources	a	Assessment of socio-economic impacts on water resources and their uncertainties under changing climate	DPRI, Kyoto Univ. Associate Professor	Kenji Tanaka
	b	Assessment of climate change impacts on the social-ecological systems of water resources and hydrological cycles	IIS, the Univ. of Tokyo Professor	Taikan Oki
(iii) Climate change impacts on ecosystem and biodiversity	a	Assessment of climatic impacts on ecosystem and biodiversity	Graduate School of Life Science, Tohoku Univ.Professor	Toru Nakashizuka
	b	Economic evaluation of ecosystem science	Graduate School of Life Science, Tohoku Univ.Professor	Toru Nakashizuka
	c	Eco-climate system in Northeastern Eurasia and Southeastern Asian tropics: Impacts of global climate change	ISEE, Nagoya Univ. Associate Professor	Tomo'omi Kumagai
	d	Assessment of multiple effects of climate change on coastal marine	Hokkaido Univ. Graduate School of Environmental Science, Professor	Yasuhiro Yamanaka

Environment and Energy Division
Research and Development Bureau
Ministry of Education, Culture, Sports,Science and Technology-JAPAN

3-2-2 Kasumigaseki, Chiyoda-ku,Tokyo 100-8959, Japan
URL:http://www.mext.go.jp/english/

Contact Point

Program for Risk Information on Climate Change(SOUSEI)
Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

3173-25 Showa-machi, Kanazawa-ku
Yokohama, Kanagawa, 236-0001, Japan

Email : sousei_info@jamstec.go.jp
URL:http://www.jamstec.go.jp/sousei/english/

2016. 8
VEGETABLE OIL INK
R70

SOUSEI


Program for Risk Information on Climate Change

~ Generation and utilization of climate change projection information and risk information available to Japan, Asia and the World ~

SOUSEI



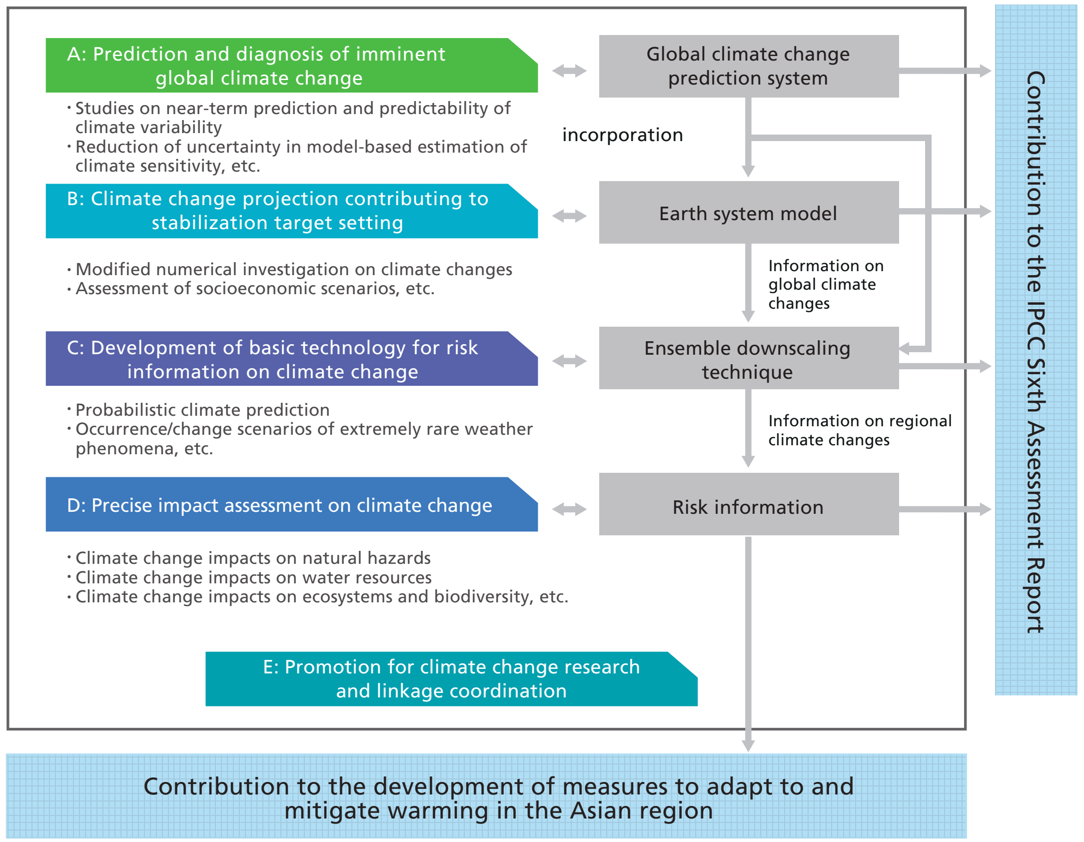
MEXT MINISTRY OF EDUCATION, CULTURE, SPORTS, SCIENCE AND TECHNOLOGY-JAPAN

Outline

Program for Risk Information on Climate Change

Overview

Our program aims to construct and establish the technology for projection of occurrence probability and the precise impact assessment on climate change, so as to generate information which is indispensable for risk management. Further, we promote the scientific assessment on the stabilization target setting and conduct the various assessments on climate change, through the reduction of the uncertainty in model-based estimation of climate sensibility and the socio-economic researches coordination, etc.



PD(Program Director)supervises the program so that it is carried out efficiently and effectively, and he handles the overall coordination of the program. A PO(program officer) is assigned to each theme to assist the PD in managing the progress of research topics and adjusting research plans, etc.

PD / PO (Theme A, C)
Akimasa Sumi
Special Advisor to MEXT
President NIES

PO (Theme B)
Mitsuo Uematsu
Special Advisor to MEXT
Professor/ Director
International Advanced Research
AORI

PO (Theme D)
Hideo Harasawa
Special Advisor to MEXT
Vice President
NIES

Theme A

AORI

Prediction and diagnosis of imminent global climate change

Representative: **Masahide Kimoto**

Vice Director/Professor, AORI, the University of Tokyo

【Research Topics】
- Understanding mechanisms of climate variability and change
- Development of an integrated prediction system for global climate studies

● Related Organizations:
AORI , JAMSTEC , NIES

Theme B

JAMSTEC

Climate change projection contributing to stabilization target setting

Representative: **Michio Kawamiya**

Director, Project Team for Risk Information on Climate Change, JAMSTEC

【Research Topics】
- Long-term global climate change projection based on diverse scenarios
- Obtaining scientific perceptions on large-scale variations and modifications of climate

● Related Organizations:
JAMSTEC , CRIEPI

Theme C

University of Tsukuba

Development of basic technology for risk information on climate change

Representative: **Izuru Takayabu**

Director, Atmospheric Environment and Meteorology Research Department, Meteorological Research Institute (MRI)

【Research Topics】
- Probabilistic climate prediction for risk assessment
- Producing a standard climate scenario by using super high resolution models

● Related Organizations:
univ of Tsukuba , MRI , NIED ,
AORI , ISEE CIDAS

Theme D

Disaster Prevention Research Institute, Kyoto University (DPRI-KU)

Precise impact assessments on climate change

Representative: **Eiichi Nakakita**

Vice Director/Professor, DPRI, Kyoto University

【Research Topics】
- Climate change impacts on natural hazards
- Climate change impacts on water resources
- Climate change impacts on ecosystem and biodiversity

● Related Organizations:
DRRI ,
univ of Hokkaido,
Tohoku univ ,
IIS,Titech, ISEE ,
NARO , ICHARM , NIES

Theme E

JAMSTEC

Promotion for climate change research and linkage coordination

Promotion for e ective researches on climate change

Representative: **Michio Kawamiya**
Director, Project Team for Risk Information on Climate Change, Strategic Research and Development Area, JAMSTEC

- Support for program implementation and outreach
- Support for forming common recognition on climate change risk information
- Establishment of a system required for providing information and advice on climate change risk

Message

Message from Program Director

Climate change due to anthropogenic global warming is a serious problem for human society in this century. In the past, we used to concentrate our attention on the study of mechanisms of global warming and its impacts on our society. However, the impacts of climate change due to global warming have recently been well noted all over the world, and it is widely agreed that more attention should be paid to actions to mitigate and adapt to these impacts. Therefore, we must present quantitative information on risks related to climate change with consideration for the uncertainty in the numerical model simulations of the future climate. In order to achieve this goal, we must accelerate research to develop a climate model and reduce the uncertainty in the simulation of the future climate.
This is the reason why the Program for Risk Information on Climate Change was launched in 2012. It is a five-year project that will end this fiscal year.

In the beginning, there existed some skepticism about whether we could produce reliable risk information because our climate model is not perfect and we cannot reduce uncertainty within two or three years. However, many interesting and important results have been obtained. For example, new methods such as Event Attribution have been developed. Event Attribution can estimate a change of probability in a given extreme weather event, although there are several assumptions which need to be examined carefully. In order to evaluate the risks of climate change, we have developed a methodology using a “maximum impact scenario“ in water-related disaster issues.

It is significant point to be emphasized that a new dataset called d4PDF (database for Policy Decision making for Future climate change) is being produced in collaboration with different research areas in this program. By using this dataset, we can estimate the impacts of climate change given a temperature increase of 4°C. It should be noted that we can estimate a change in the probabilistic distribution of a certain physical variable. These research achievements are displayed in this brochure and are used in various research organizations and governments. Further, these researches attract global attention, for instance, such as from UNFCCC.

The Paris Agreement was adapted in 2015 at COP21 held in Paris. It is a new international framework in which all nations and regions participate. Each country has submitted its own INDC (Intended Nationally-Determined Contributions) and has to realize its contribution. The INDC will be reviewed every five years. For this reason, impacts due to climate change must be more accurately estimated, and this can be accomplished by improving the climate model and increasing the number of samples in an ensemble method. This is an area where the results produced by this program will be developed further.

I would like to express my sincere thanks for your help and support and hope that a successor program for this project will be started in the next fiscal year.

Program Director (PD)
Akimasa Sumi (Special Advisor to MEXT),
President, National Institute for Environmental Studies (NIES)

Understanding the current climate changes and predicting the future – Providing the basic information for measures against climate changes

Representative: **Masahide Kimoto** Vice Director/Professor, AORI, the University of Tokyo

To take measures against global warming which is in progress, we need reliable prediction information on the types and probability of climate events that are expected to take place in the future. Under this theme, we have developed a system that can predict climate variability on various timescales, from El Niño over a half year to global warming over 10 to 100 years, by making more sophisticated climate models which are tools to obtain prediction information and by incorporating atmosphere and ocean observation data into the models. Moreover, we assessed the contribution of anthropogenic factors to the ongoing climate changes by conducting numerical experiments using this system, and tried to provide risk information on global warming to society.

Is this year's heat wave caused by global warming?

It is often said that disasters occur when least expected. Even though the frequency may be low, summers with heat waves and winters with heavy snow come inevitably as a result of the natural climate variability of the earth, and we cannot attribute individual climate events only to global warming. However, global warming is slowly progressing and changing the frequency of anomalous or extreme weather phenomena.

By conducting a large number of elaborate simulations, we can understand the mechanism of climate events and calculate the contribution to global warming. In Theme A, we have promoted such research which is called "event attribution." We were able to convey to society messages such as: "The probability of a heat wave such as that in 2013 would have been much lower without global warming. In other words, global warming is increasing the risk of heat waves by x%." At the same time, the research promoted an understanding of the relationship between natural variability and global warming risk. By conducting 10 times more simulations than before, we demonstrated the ability of this approach to generate probability information on global warming risk, and using this methodology, we compiled the "d4PDF" dataset* as cooperative work for Themes A-D. (*) Described in detail on p.12.

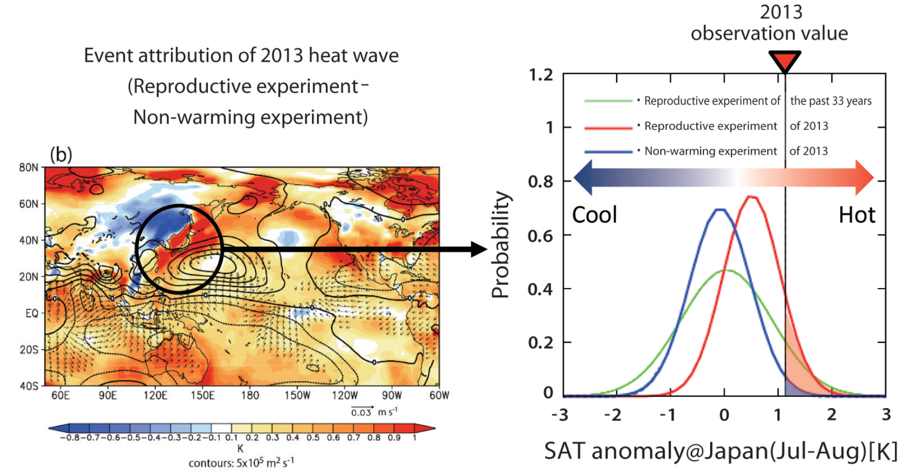


Fig. 1: Event attribution
We conducted a reproductive experiment of 100 members with different initial values, giving boundary values (sea surface temperature and sea ice) observed in a global atmosphere model, and we conducted an experiment in which factors causing warming were excluded from the boundary values. We assessed the contribution of warming to the occurrence probability of less frequent anomalous weather events by comparing the probability density distribution of meteorological elements obtained from these experiments. The figure on the left shows the differences in the surface air temperature (colors), 850 hPa stream function (contours), and 200 hPa divergent winds (arrows) obtained in the reproductive experiment on the heat wave in Japan in 2013 and the non-warming experiment. The figure on the right compares the surface air temperature PDF near Japan obtained in the reproductive experiment (red) and non-warming experiment (blue). Green shows a climatological PDF of the same variables obtained by a longer term reproductive experiment. The probability of a hotter summer than was observed in 2013 (shown in the top part of the figure) is only 1.7% in the overall non-warming case. In the actual (warmed) conditions, however, the probability is estimated to be 12.4%, indicating that warming is increasing the risk of heat waves. (Imada et al. 2014, Bulletin of the American Meteorological Society)

Has global warming stopped?

Not only individual climate events but also the relationship between global warming and climate trends observed in recent years often attracts the attention of society. The plateau in the time series of the global mean surface temperature over 15 years after the record-setting El Niño in 1998 is known as the global warming "hiatus." It has become a major topic of social and scientific interest. In addition, frequent cold winters in recent years, despite global warming, are often reported by the media. Is global warming actually progressing?

The research on Theme A has also tried to provide a scientific answer to these questions. With regard to the hiatus, we found that the ocean interior temperature is rising steadily although the surface air temperature stays at the same level. It is believed that the temperature rise has temporarily halted primarily in the sea surface as a result of natural fluctuations of heat transportation inside the ocean. We also found that the impacts of global warming are increasing, rather than decreasing, as a result of an analysis during recent decades. Regarding cold winters, the research demonstrated that a decrease in sea ice over the Arctic Ocean due to global warming is causing a change in a pressure pattern that increases the intensity of the Siberian anticyclone. The research also indicated that it cannot be said that the Northern Hemisphere will experience more cold winters if global warming progresses because the Arctic oscillation, another important natural fluctuation, makes a larger contribution after the progress of global warming.

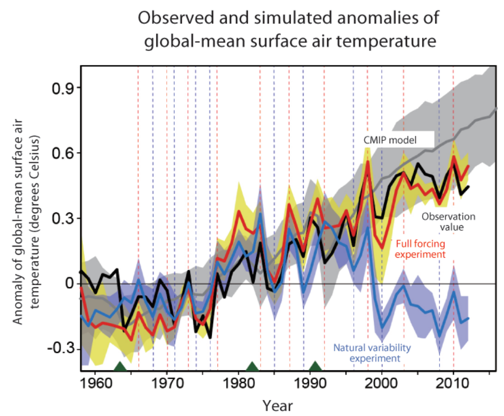


Fig. 2: Reproduction of the hiatus and attribution analysis
We successfully reproduced the hiatus in global temperature rise since 2000 in a simulation using a global climate model (red line). Moreover, we found that natural climate fluctuations contributed to global temperature changes to a non-negligible degree at a range of 27%-47% over the period from 1980 to 2010. Such reproduction of past climate variations and attribution analysis provide useful information for assessing reliability of future climate prediction. (Watanabe et al. 2014, Nature Climate Change; Press release on September 1, 2014)

The new prediction system expands not only future information but also past information

Climate models are making steady progress. In Theme A, we developed a new model for use in the next phase of the Coupled Model Intercomparison Project. We decided to introduce a new method known as Ensemble Kalman Filter (EnKF) to "data assimilation" to incorporate observation data. This method involves a larger amount of calculation than conventional methods, but it can incorporate atmospheric and oceanographic data simultaneously and makes it possible to handle variables which are technically difficult to incorporate, such as sea ice. In addition, the method increases the accuracy of variables which are different from the incorporated variables. This property allows us to reconstruct pre-1950's climate conditions, for which upper-air observation data and ocean interior observation data are very scarce, using relatively abundant surface observation data. Using a prototype of the "150 Year Climate Reanalysis" complied in Theme A, samples of anomalous climate events and extreme weather will increase, and the understanding of multidecadal climate variability will be improved. Furthermore, attribution and risk assessment of extreme weather events such as Muroto Typhoon (1934) will become possible when combined with a downscale approach, etc. The coverage of a wider range of past phenomena directly leads to the improvement of the reliability of future predictions.

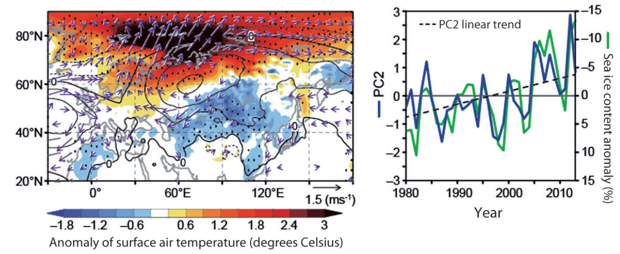


Fig. 3: Attribution analysis of frequent cold winters in mid-latitude regions of the Eurasian Continent
A large ensemble simulation using an atmospheric model revealed that the cold winter probability in mid-latitude regions of the Eurasian continent has more than doubled due to the rapid decrease of sea ice in the Arctic Ocean in recent years. Complemented by an analysis of future prediction simulations using climate models around the world, it is suggested that the increase in cold winters in recent years is a transitional phenomenon that temporarily occurs in the warming process. The figure shows spatial patterns obtained from a principal component analysis of observed surface air temperature anomaly in winter (left: surface air temperature (colors), associated sea level pressure (contours: 1 hPa interval), and surface wind (arrows) anomalies) and their time coefficients (right). The time coefficients agree well with interannual changes in sea ice anomaly (time series in green) averaged over the Barents Sea and the Kara Sea, thereby indicating effects of the Arctic sea ice on mid-latitude climates. (Mori et al. 2014, Nature Geoscience; Press release on October 27, 2014)

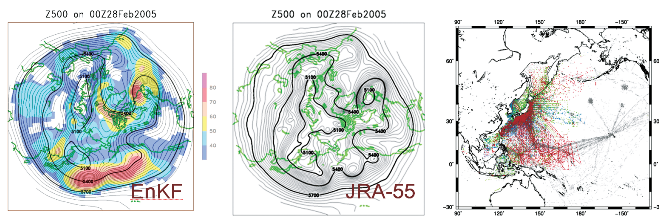


Fig. 4: Toward 150-year climate reanalysis
The figure shows a comparison of a 500 hPa (approx. 5 km above surface) height field in the case of one reproduced only from surface atmospheric pressure data using a new data assimilation method (EnKF; left) and the case of the operational analysis provided by the Japan Meteorological Agency (center). The shades in the left panel indicate estimates of analysis error based on the ensemble method. The rightmost panel shows distributions of upper ocean temperature data before World War II. The colored part shows data provided by Japanese institutions. We are also working to digitize climate observation data collected by the former Imperial Japanese Navy. Such a long-term attempt at a coupled ocean-atmosphere system is unprecedented.

Towards reducing uncertainty in climate prediction

One of the serious issues of global warming simulation has been divergent views of temperature rise and rainfall changes depending on the climate models used for prediction, even using the same scenario of increasing concentration of carbon dioxide. Reduction of such uncertainty is needed to take measures against global warming appropriately. In Theme A, we have promoted research to address this issue, called "climate sensitivity," by building a large ensemble of models within the range of uncertainty and by using a high-resolution model with detailed representation of clouds which primarily control the climate sensitivity. With regard to the "key processes" clarified by these approaches, we demonstrated that we can limit the range of uncertainty using observational data. Moreover, we indicated that horizontally small-scale clouds, which could not be represented explicitly in conventional models, can enhance the climate sensitivity and play an important role in reducing uncertainty.

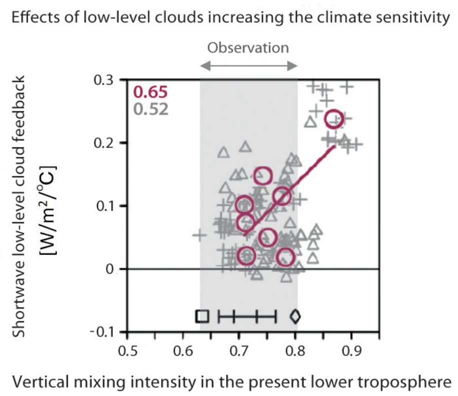


Fig. 5: Limiting uncertainty of a key process that controls climate sensitivity
Global warming simulations using a number of climate models revealed that low-level clouds increase the climate sensitivity and that their effects are related to vertical mixing intensity in the present lower troposphere. Moreover, it is suggested that we can limit the range of uncertainty of this process by referring to observational data. (Kamae et al. 2016, Journal of Climate)

Theme B ▶ Climate change projection contributing to stabilization target setting

How much carbon dioxide (CO_2) reduction do we need in order to mitigate global warming? – Estimating uncertainties in projection and their impacts on the future economy

Representative: Michio Kawamiya Director, Project Team for Risk Information on Climate Change, JAMSTEC

We have been investigating the impacts of reduction in anthropogenic CO_2 emission on the global environment under various scenarios. One of the greatest obstacles to the assessment is the uncertainties in the projection. This is why many of our efforts have been directed at obtaining not only plausible projections of the global environment but also the projections' possible ranges, using an earth system model which is an ocean-atmosphere coupled climate model with biological and chemical processes embedded.

Grasping uncertainties: A key to global warming mitigation?

The fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) clearly shows a proportional relation between transient temperature rise and cumulative CO_2 emission by human activities. The slope of the proportional relation is called transient climate response to emission (TCRE), and it demonstrates how warm the earth is likely to be due to the anthropogenic emission of CO_2. An average value of TCRE indicates that carbon emission of 400 PgC (1 PgC = 1 billion tons of carbon) corresponds to a rise of 1 degree Celsius in global mean surface temperature.
The target of 2 degrees Celsius, which is often referenced in international conferences, etc., on climate change, is aimed at suppressing temperature rise below 2 degree Celsius relative to the pre-industrial era. To meet the target, cumulative CO_2 emission has to stay below 800 PgC, but half of this has been already emitted as of the year 2010. While it is clearly not an easy task to meet the target, the uncertainty in TCRE is still significant. It is possible that, with the emission of 800 PgC, the temperature rise will surpass even 2.5 degrees Celsius; on the other hand, it is equally possible that it will stay below 1.5 degrees Celsius. It is of great importance to grasp what this uncertainty means to socioeconomics.

Estimating impacts of earth system uncertainties on socioeconomics

We pick up a concentration scenario called RCP4.5, which leads to a medium degree of warming amongst the four scenarios adopted in AR5, to examine socioeconomic impacts of the uncertainties in the projection. An estimate of how much CO_2 emission corresponds to the RCP4.5 concentration path contains uncertainties because it depends on the ability of terrestrial vegetation and oceans to absorb anthropogenic CO_2. Fig.1 shows the uncertainty range evaluated by our earth system model (ESM), which is an ocean-atmosphere coupled climate model with biological and chemical processes embedded. Around the end of this century, the lower bound path shows an emission close to null, that is, zero-emission. On the other hand, the upper bound path still retains an emission of about 5 PgC, half of the current emission, illustrating the huge difference between the lower and upper paths.
The upper bound path corresponds to a low TCRE (the earth can "resist" warming), and the lower bound path to a high TCRE (it can easily be warmed!). Using our ESM, we investigated what the differences between the two mean to global socioeconomics. The gross domestic product (GDP), an often-used index for economics, is 4% higher for the upper path than for the lower. While the 4% difference may appear relatively small, it should be borne in mind that this insensitivity is underpinned by the three-fold difference in carbon price, which is a measure of carbon tax, displayed in Figure 2a. A remarkable difference can also be seen in primary energy demand (Figure 2b), where introduction of biomass energy is 50% higher in the lower path around the end of this century. The 4% difference in GDP is a conclusion premised on the assumption that efforts toward CO_2 reduction, such as introduction of biomass energy, are implemented smoothly in the lower path with a three-fold carbon price.
In order to pursue the best combination of mitigation measures including observation and projection of the global environment and renewable energy development, it is required to link uncertainties in projection and mitigation costs as shown above. The results presented here have been also reported in the subsidiary board meeting for United Nations Framework Convention on Climate Change (UNFCCC) in Bonn, May, 2016 attracting participants' attention.

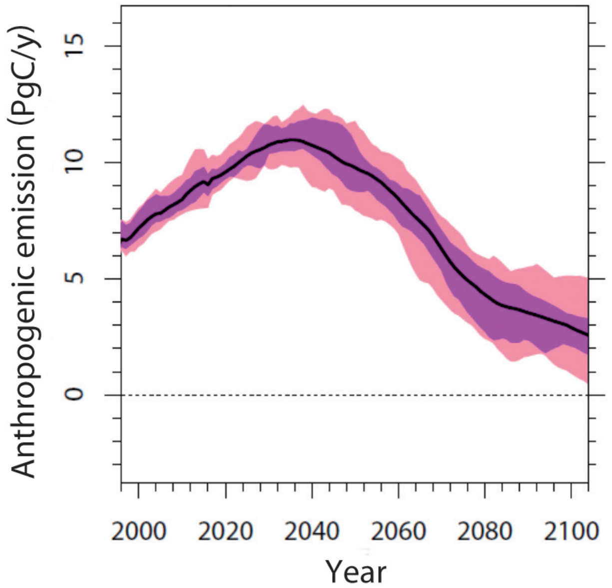


Fig. 1: Time series of annual emissions of anthropogenic CO_2 from fossil fuels compatible with the RCP4.5 concentration scenario. Shades indicate ranges of uncertainty. Purple shows the 68% probability range and pink 90%. The black line represents the average. Modified from Tachiiri et al. (2013).

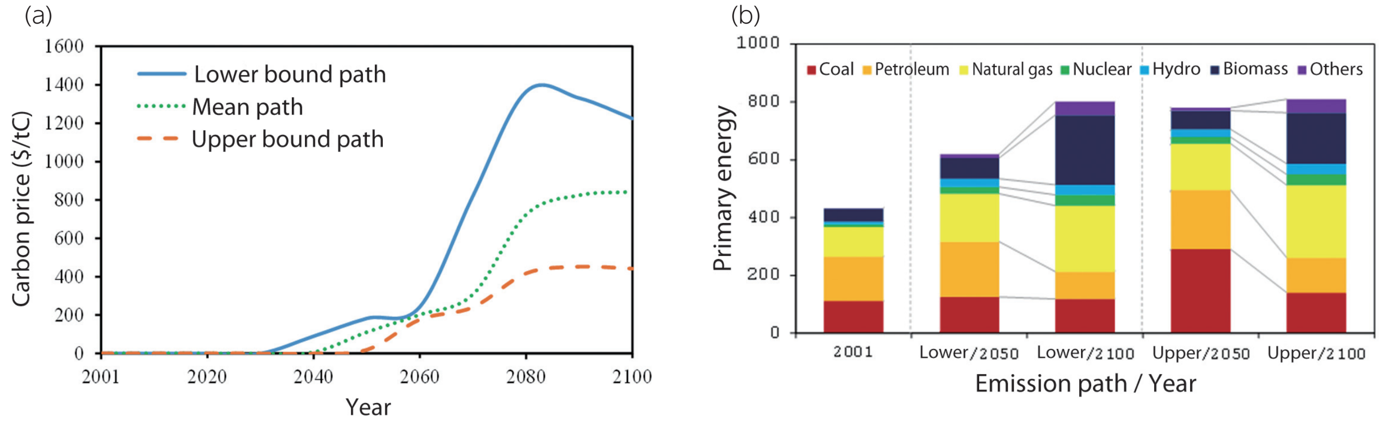


Fig. 2: (a) Projected time evolution of carbon price based on RCP4.5 corresponding to the lower bound, mean, and upper bound paths in the uncertainty range shown in Figure 1. (b) Primary energy demand in 2050 and 2100 for the lower and upper bound paths. Modified from Matsumoto et al. (2015)

Toward further improvement of climate change projection

Collaboration has been accelerated between scientists in the fields of socioeconomics and climate science since the launch of the SOUSEI project, which revealed that the future image of society is significantly dependent on the exact value of TCRE. One of the major factors generating uncertainties in TCRE is interactions between the carbon and nitrogen cycles, while others include ocean heat uptake, etc. It turns out, from comparison of the results obtained by ESMs developed by institutes around the world, that consideration of processes for nitrogen utilization by forests greatly affects evaluation of future CO_2 uptake by terrestrial vegetation (Figure 3). As we approach the release of IPCC's sixth assessment report due in 2021, it is expected that world-leading institutes will provide projection data obtained by their ESMs that incorporate processes involving the nitrogen cycle. The SOUSEI program is also developing a sophisticated ESM by introducing the nitrogen cycle and improving the physical processes of the atmosphere and ocean (Figure 4). Our hope is to contribute to implementation of climate change mitigation efforts such as those in the United Nations Framework Convention on Climate Change (UNFCCC), which is now shifting its phase triggered by Paris Agreement (*). Namely, Paris Agreement states that mitigation measures by participating countries are evaluated every five years based on the latest scientific knowledge. This means that results obtained by ESM will affect policies of participating countries in a more direct manner than ever. Importance of researches using ESM will only grow in the future.

*Paris Agreement: An agreement adopted at the 21st session of the Conference of the Parties to UNFCCC (COP21) on December 12, 2015. The aim is to suppress the temperature rise below 2 degrees Celsius relative to the pre-industrial era and further explore the possibility of staying below 1.5 degrees Celsius.

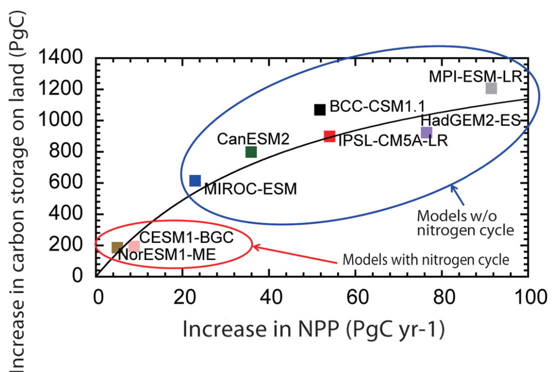


Fig. 3: Future CO_2 uptake (increase in carbon storage on land) estimated by ESMs which contributed to IPCC AR5 plotted against the response in net primary production (NPP). It is clearly seen that CO_2 uptake is closely linked with an increase in NPP and that the response is totally different between models with and without the nitrogen cycle. The square labeled "MIROC-ESM" is the model which has been developed under the SOUSEI project. Modified from Hajima et al. (2014).

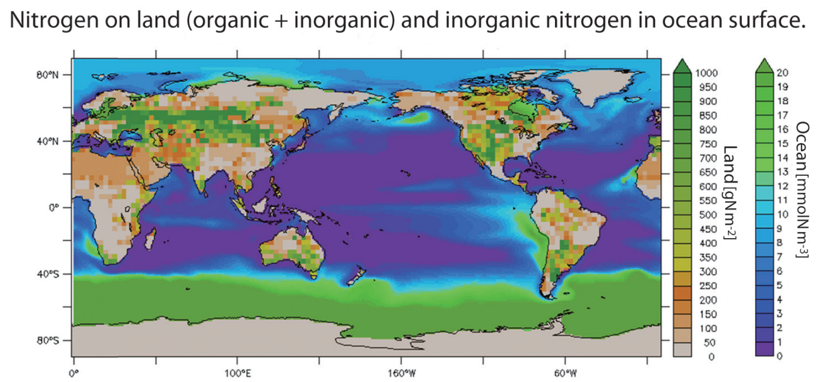


Fig. 4: Inorganic and organic nitrogen stored on land and the concentration of dissolved inorganic nitrogen in ocean surface reproduced by MIROC-ESM, an ESM developed under the SOUSEI project.

Theme C ▶ Development of basic technology for risk information on climate change

What kind of climatic hazards may happen in the future world?-Describe the "possible future scenarios" toward the uncertain future

Representative: Izuru Takayabu Director, Atmospheric Environment and Meteorology Research Department, Meteorological Research Institute (MRI)

Our objective is to prepare basic information about climatic hazards to help assess the risks from climate change. For this purpose, we need to quantify the probability of occurrence of these climatic hazards.

Probabilistic climate projection for risk assessment

There are currently many global climate models (GCMs) in the world, given the improvement of scientific understanding and computer resources. However, the assessment of the uncertainty among multiple model results is still an issue. Here, we prepare a probabilistic map of the future change in the temperature around Japan Islands. Fig. 1 indicates the increase in the monthly near-surface temperature. It shows that the temperature increase is more evident in the winter season at the northern area of Japan.

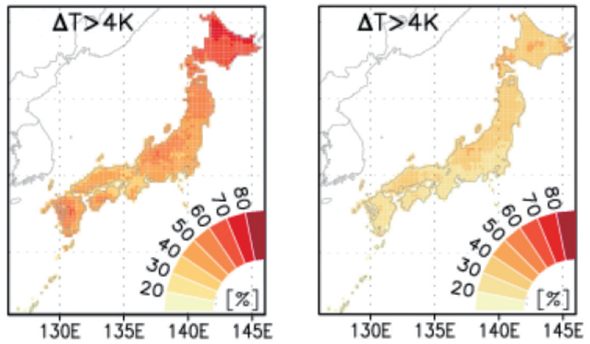


Fig. 1: Future change in the monthly mean temperature. Probability of occurrence of temperature increases more than 4 degrees during the (Left) winter and (Right) summer seasons.

Typhoons hit Japan only two to three times per year. However, we have to estimate the typhoon activity statistically for disaster prevention. Fig. 2 indicates the calculation results of an artificial typhoon trajectory. Using this method, we can simulate the probability of the typhoon track.

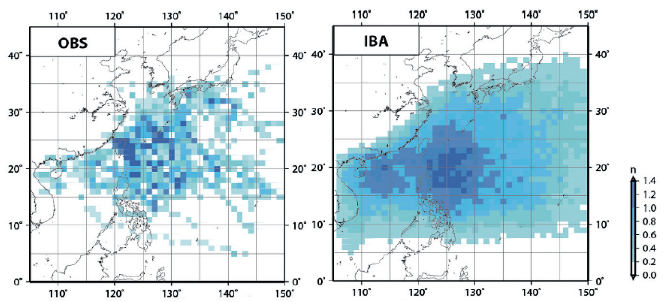


Fig. 2: (Left): Spatial distribution of frequencies of typhoon tracks deduced from the "RSMC best track data" since 1951. (Right): Same as left but for the artificial typhoon tracks simulated by the ISM-stochastic typhoon model.

Fig. 3 shows the change in annual total precipitation and precipitation extremes (annual maximum daily precipitation) estimated from a large ensemble simulation with a 60-km mesh model (Database for policy decision making for future climate change, or d4PDF). Annual total precipitation tends to increase in both the high latitudes and tropical region, and decrease in the sub-tropical region, with a high uncertainty over Japan and the Western North Pacific region. On the other hand, annual maximum precipitation increases almost everywhere, with much higher accuracy.

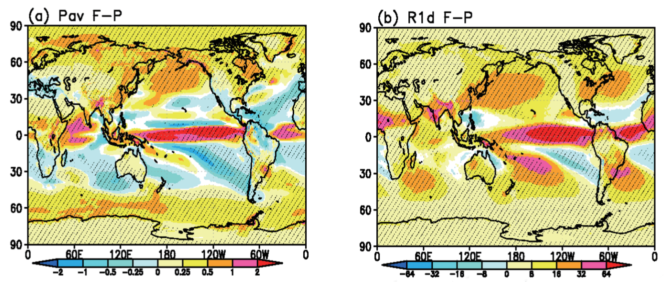


Fig. 3: Projected future change in (a) annual precipitation (mm/day) and (b) annual maximum 1-day precipitation (mm). Shading denotes the region where uncertainty is small.

Higher model resolution requires more computer resources and more sophisticated physical schemes used in the model

Here, we have developed a regional climate model (RCM) with a horizontal grid size of 2-km, which could simulate severe weather events in the future, e.g., frequency of days with precipitation exceeding 50 mm/hour (Fig.4).

A model excluding the effect of the ocean and atmosphere interactions produces a high bias in the simulation of large-scale atmospheric phenomena. The high bias in typhoon tracks simulated by an atmospheric GCM could be reduced using a newly developed atmosphere-ocean semi-coupled GCM (Fig. 5).

Fig. 6 indicates an improvement in the reproducibility of the climate around Japan area by adopting a newly developed atmosphere-ocean coupled RCM in the project.

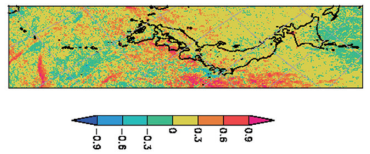


Fig. 4: Future change in the frequency of days with heavy precipitation (exceeding 50 mm/hr) in September.

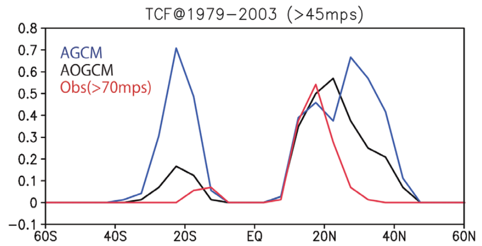


Fig. 5: Zonal average intense TCF (in 5°× 5° bins; units of (25 yr)−1). The Atmosphere Ocean Semi-coupled model (Atmospheric model) results are shown in black (blue). Observed extreme (C5: maximum wind speed > 70 ms⁻¹) TCF is shown in red.

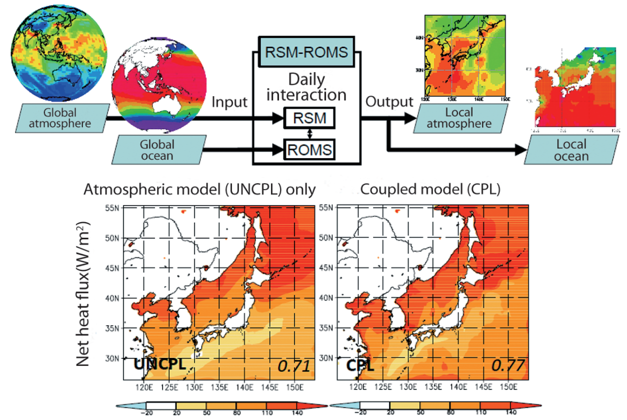


Fig. 6: Top: Schematic diagram of the coupled RSM-ROMS system. Bottom: Dynamically downscaled results with only atmospheric model (UNCPL) and coupled model (CPL). In CPL, horizontal distributions of net heat flux was downscalled with smaller scale feature similar to the observed data (modified from Ham et al. (2016); numbers in the right bottom of each figure are horizontal correlation coefficient with observation (closer to 1 is better)).

Preparation of a worst case scenario for typhoons, and extension of the research to the Southeast Asian region

In 1959, Typhoon Vera caused the deaths of over 5000 people, making it the worst typhoon case in Japan. How the intensity of such a typhoon will change under the future climate is the main interest in our project. Here, we have done high accuracy experiments using four different regional models, which all showed increases in the typhoon intensity in the future (Fig. 7).

Many developing countries in the tropical or sub-tropical region are recognized to be very vulnerable to climate change because the rainfall associated with typhoons and monsoons may become severe in the future warmer climate. However, the design of adaptation plans in these countries may be delayed by the lack of climatic hazard information. In this project, we invited researchers from the Philippines, Indonesia, Viet Nam, Malaysia, and India for about two months, guiding them to learn our Non-hydrostatic Regional Climate Model (NHRCM), and working together to determine the future climate change in their countries. NHRCM would be installed in their computer systems to allow them to continue the research in their countries. Fig. 8 indicates the change in the 95th percentile value of the daily precipitation around Southeast Asia. Heavy precipitation is projected to increase in most areas, which may exceed 40% in some locations.

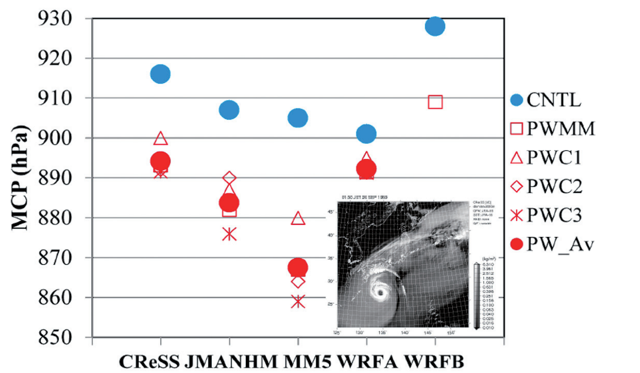


Fig. 7: Minimum central pressure of Typhoon Vera simulated using CReSS, JMANHM, MM5, and WRF. Blue dots indicate the simulation with the present condition. Red symbols indicate the simulation results under the future condition.

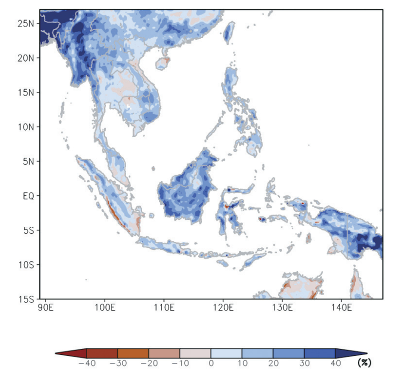
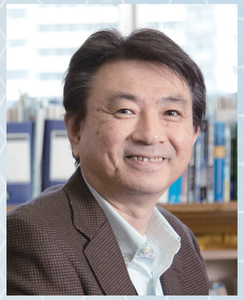


Fig. 8: Future change in the 95th percentile value of the daily precipitation (expressed as percentage difference) around Southeast Asia.

How will Japan and the world change at the end of the 21st century due to climate change? - Providing helpful information to society for adaptation measures

Representative: Eiichi Nakakita Vice Director/Professor, DPRI, Kyoto University



How do typhoons, floods, landslides, and river flows change as a result of global warming? In this research theme, we reveal the relationship between global warming and natural disasters from a scientific viewpoint and project how severe such disasters will become during the next 100 years. For this purpose, we employ two approaches. One approach is to quantitatively assess the degree of climate change's effects on natural disasters, such as typhoons and flooding, through estimating the probabilities of such hazards. The other approach is to assess the impact of climate change in the worst-case scenarios by taking into account the severest meteorological forcings such as super-typhoons. Recently, devastating, unprecedented disasters have been occurring frequently not only in Japan but also in countries around the world. We will study how the worst-class disasters affect human society from both the scientific and the engineering aspects, and we will provide basic information for the adaptations necessitated by the anticipated climate change.

Climate change impacts on natural hazards

We are now able to quantitatively estimate heavy rainfall and strong winds for different potential tracks of typhoons by using a "potential vorticity inversion" typhoon-bogus method that can relocate the initial position of a typhoon vortex at any location. In addition, by using a pseudo-global warming experiment, we are able to simulate how disastrous typhoons of the past would be intensified under the global warming conditions and to assess how global warming will strengthen the worst-case typhoons equivalent to Typhoon Vera (1959) (known as Isewan Typhoon) and Typhoon Songda (2004, Typhoon No.18). By using the meteorological data from the simulations of Isewan Typhoon, we investigated the conditions for causing the highest-class river discharge and the climate change impacts on the discharge. The actual track of Isewan Typhoon in 1959 can be captured well by the simulated track in control experiment No. 9, which indicates that the actual Isewan Typhoon is the worst case for spawning the highest amount of the river discharge in the Yodogawa River basin. It was also found from the pseudo-global warming experiments for Isewan Typhoon that the maximum amount of river discharge increases by 20% under global warming, and that the typhoon track that produces the maximum amount of discharge under global warming conditions is shifted eastward. The flooding caused by Typhoon Man-Yi (2013, Typhoon No. 18) exceeded the maximum amount simulated in the pseudo-global warming experiments, and it was the highest amount of discharge in recorded history. Thus, we need to understand that the worst-class flooding events actually occurred in recent years.

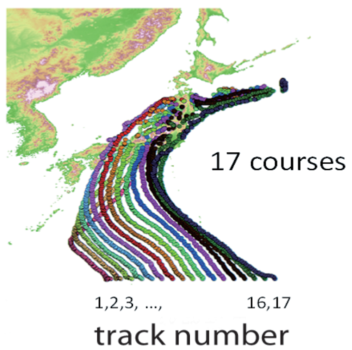


Fig. 1: Tracks of the simulated typhoons in the track-ensemble experiments for Isewan Typhoon

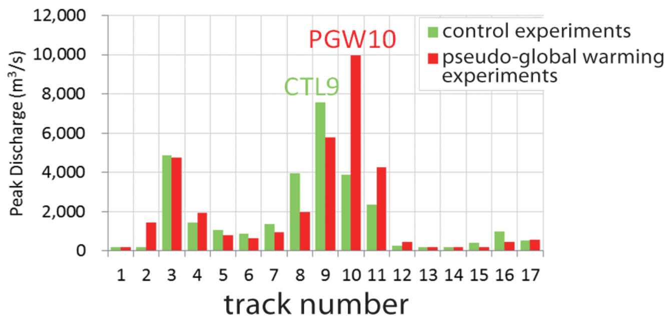


Fig. 2: Peak discharge at the Hirakata point versus typhoon track in the control and the pseudo-global warming experiments

A flood risk curve, which shows the relationship between the annual maximum economic damage and its exceedance probability, was developed for economical evaluation of inundation risk, which was derived through ensemble flood-inundation simulations and estimation of the inundation damage. It provides a basis for selecting an adaptive measure from among various alternatives.

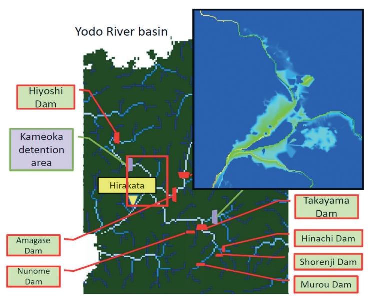


Fig. 3: Flood inundation simulation in the Yodo River basin

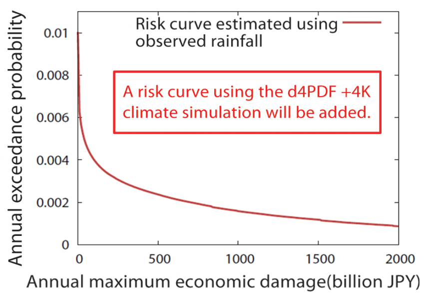


Fig. 4: Inundation risk curve in the Yodo River basin

Future changes in storm surge are projected by d4PDF results, MRI-AGCM scenario runs, and the global stochastic tropical cyclone model (GSTM), respectively. The long-term changes in storm surge height based on d4PDF indicate that cases of extreme storm surge height will increase in three major locations in Japan: Tokyo Bay, Osaka Bay and Ise Bay. Extreme storm surge height, which has a 100-year return period in the present climate, is projected to occur more frequently with one-half to one-third shorter periods, corresponding to a 30- to 50-year return period in the future climate. The projection of storm surges depends highly on typhoon tracks, and uncertainty is large. However, the future changes in storm surge height for periods longer than 10-year return periods are significant in Osaka Bay and Ise Bay.

Future changes in ocean waves are projected by MRI-AGCM scenario runs using global spectral wave models and statistical models, respectively. The future changes in wave height under the RCP8.5 scenario show a 2 m increase with a 10-year return period in the future climate. The future change signal is consistent among the ensemble experiments in the western North Pacific.

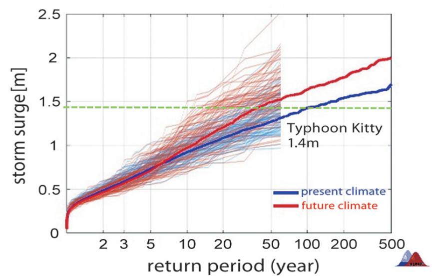


Fig. 5: Long-term changes in storm surge in Tokyo Bay (blue: present climate, red: future climate; unit: m)

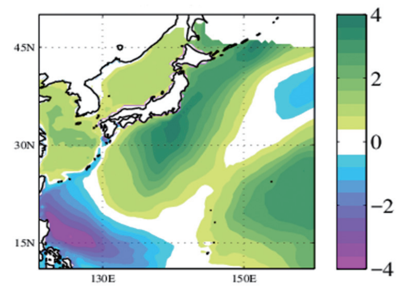


Fig. 6: Future change in wave height with a 10-year return period (unit: m)

We simulated the inundation area and depth using the Rainfall-Runoff-Inundation model (RRI model) for the Pampanga River basin in the Philippines. We selected 2001 and 2087 as the worst-case years with the largest inundation area under the present and future climate scenarios, respectively, each of which covers a period of 25 years. As a result of comparing the two worst cases, we found that the rice crop damage may increase by 20% under the future climate scenario.

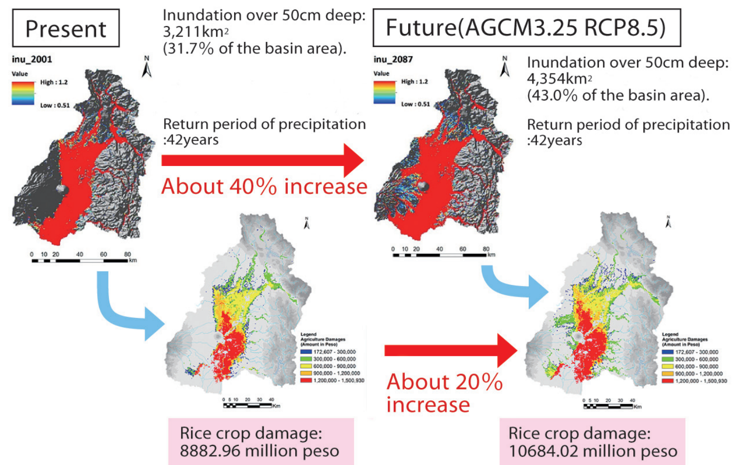


Fig. 7: Comparison of rice crop damage in the Pampanga River basin under the present and future climate scenarios

Climate change impacts on water resources

When the climate changes due to global warming, the rain amount and rain patterns change significantly. It is also possible that what formerly fell as snow will change into rain. In Japan, which has many mountainous regions, it is anticipated that this will cause a great change in the river regime (i.e., seasonal pattern of river flow). An integrated in-land hydrological model was used to assess the impact of climate change on the river regime. The river regime change is noticeable in snowy region of Japan (shown in red in Figure 8). Based on the river regime change information, the hydropower generation potential was estimated for major hydropower dams. It is suggested that the hydropower generation potential will decrease (shown in blue in Figure 9) in many parts of Japan excluding Hokkaido and the northern part of the Tohoku region.

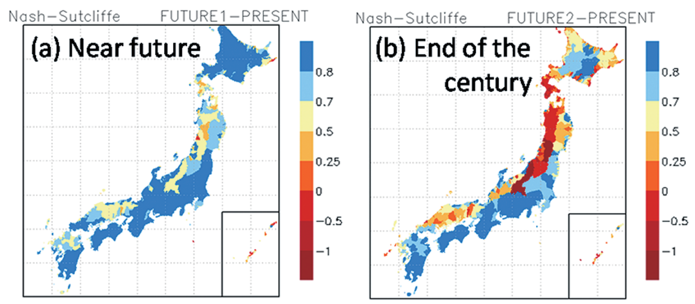


Fig. 8: Japanese river regime change due to climate change

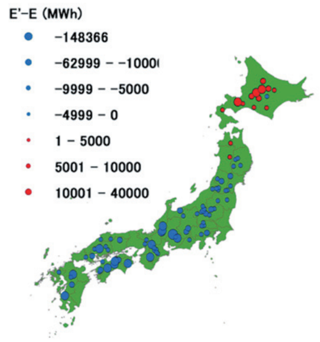


Fig. 9: Hydropower generation potential change due to climate change

Future changes in hydrological drought caused by climate change were estimated based on a simulation using a global hydrological model that can account for human activities (e.g., dam operation and water withdrawal for irrigation). The simulation was performed for two cases: with consideration for human activities (e.g, dam operation, water withdrawal for irrigation, etc.) (HI) and without consideration for human activities (NAT). It was projected that the number of drought days will increase in most of the regions around the globe in both cases. The long-term change and the short-term variability of drought days were smaller in the case that considered human activities (HI) compared to the case without consideration for human activities (NAT). This finding implies that water management can mitigate future changes in drought days.

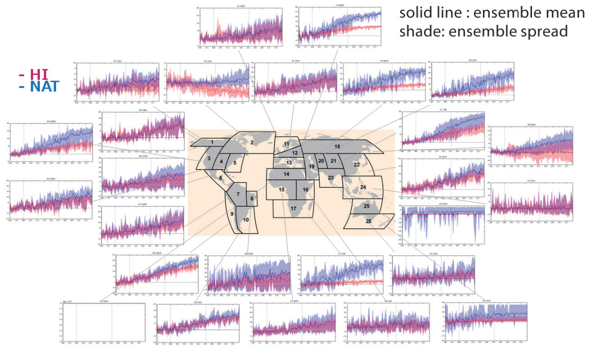


Fig.10 Time series variation of regional median drought days (1980-2099)

Climate change impacts on ecosystems and biodiversity

Global warming affects ecosystems and biodiversity. We produced a statistical model to estimate the future distribution of alpine climate (i.e., areas equivalent to the present condition of the alpine zone). Most of the areas where alpine vegetation is presently distributed in Honshu Island will be lost in 2100 (red areas), and very few will remain (yellow areas).

As for the future prediction of terrestrial ecosystems, we developed a new model named S-TEDy (SEIB-DGVM-originated Terrestrial Ecosystem Dynamics model), structured on SEIB-DGVM, a dynamic global vegetation model which explicitly incorporates ecosystem processes such as local light competition among individual trees, seed dispersal, bud break, disturbance, and death of trees, from canopy to global scales. The S-TEDy incorporates more detailed submodels of biochemistry, water movement in plants, soil nutrient cycling, and heat and water transport in soil, which enables us to reproduce abnormal process in terrestrial ecosystems such as nitrogen starvation and mass mortality of trees caused by climate change in more detail, by applying it to a tropical rainforest in Asia and a boreal forest in eastern Siberia.

Also, focusing on ocean acidification, which is caused by intrusion of CO_2 into the ocean, we assess and project how coral reefs and seaweed beds are changing in response to global warming and ocean acidification. We newly compiled a database on the historical distribution records in the presence and absence of Japanese seaweeds. Using the relationship between the distribution data and nine environmental variables including sea surface temperature, water characteristics, and coastal structures, we constructed seven methods of species distribution (statistical) models to predict suitable habitat distributions. By applying the projected values of Miroc4h sea surface temperature to the models, we predicted the inhabitable probability. Finally, we ensembled the values and obtained predictions for the 1990s, 2010s, and 2030s. As a result, we found that a temperate species shows a poleward range shift with a decrease in its inhabitable area, and a southern species undergoes a poleward shift with an increase along the northwest coast of the Kyushu area.

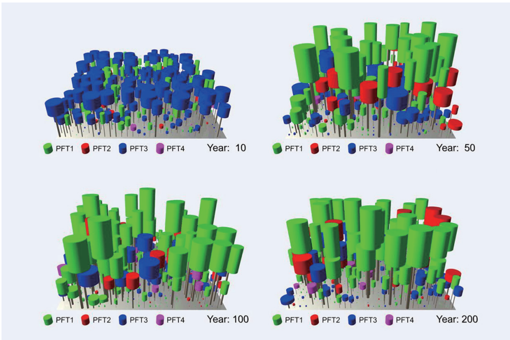


Fig. 12: Terrestrial Ecosystem Dynamics model (S-TEDy)

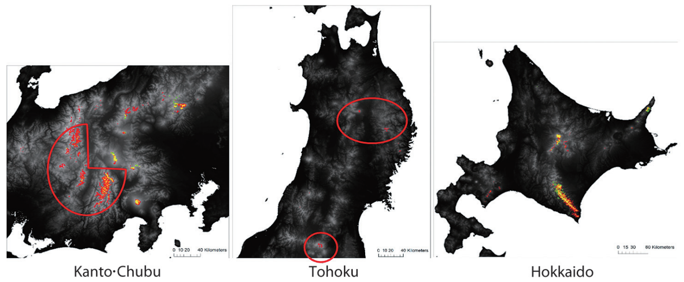


Fig. 11: Present and future (MRI-CGCM3 (RCP 2.6) in 2100) distribution of the areas with alpine vegetation; Red indicates the areas where climate conditions for alpine vegetation will remain, and yellow indicates the areas where it will be lost

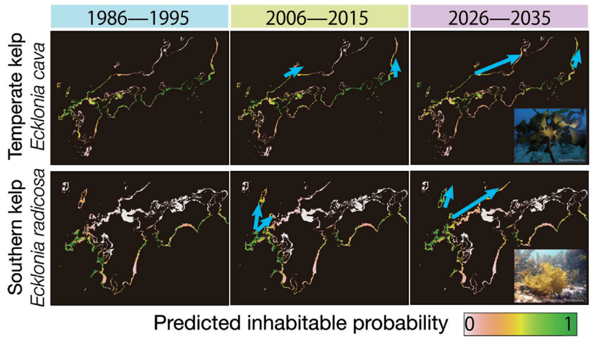


Fig.13: Predicted inhabitable probabilities of a temperate and a southern algal species from the past to the near future. The lowest and the highest inhabitable probabilities are shown in brown and green, respectively. Arrows represent expansions of the species' ranges

Delivering science to society by producing concrete estimates

Theme D aimed to forecast the risk due to the effects of climate change on natural hazards, water resources, ecosystems, and biodiversity using the latest future climate projection information. This involved not only the application of existing assessment models but also involved many scientific challenges as well. Under the data limitations such as limited ensemble number, we endeavored to assess the changes in extreme events together with uncertainty quantification. Also, economic damages were evaluated in the worst-case scenario, particularly in the case of typhoons, which cause the most serious weather-related damage in Japan. Final outcomes are being utilized in establishing adaptation guidelines in the related Japanese Ministries such as the Ministry of Land, Infrastructure, Transportation and Tourism. In this way, Theme D is contributing to governmental adaptation strategies and guidelines.

database for Policy Decision making for Future climate change

Project summary

Designing an adaptation plan for climate change requires an estimation of the uncertainty in climate projections, which needs information on the frequency of occurrence of natural disasters. However, there is only a small ensemble of climate change projection data currently available, and the reliability is still not enough for assessing severe weather statistically. Through the collaboration among all themes of SOUSEI program, we have done simulations in the order of 100 ensembles. This dataset is called d4PDF (database for Policy Decision making for Future climate change), which enables us to conduct a statistical analysis of extreme weather. The use of d4PDF is expected to help improve the understanding of uncertainties in the past and future climate, as well as related impact studies. The projected climate change information from this dataset can also be used in the adaptation plans of many stakeholders.

d4PDF HP (in Japanese)	http://www.miroc-gcm.jp/~pub/d4PDF/
Symposium HP (in Japanese)	http://www.jamstec.go.jp/sousei/jp/event/others/d4PDFsympo/

Increased accuracy in the projection of heavy precipitation

As the ensemble number of the model experiments increases, the probability density becomes smooth (Fig. 1), which suggests increased accuracy in the projection. The use of multiple ensemble experiment results allows us to discuss the occurrence of heavy precipitation, which are the very rare events.

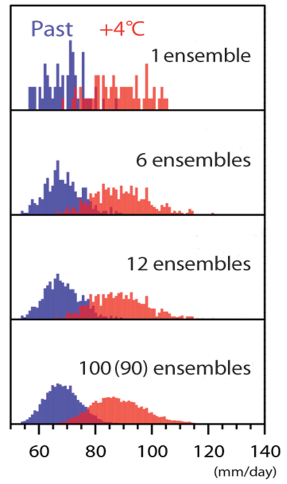


Fig. 1: Probability density function of the annual maximum daily precipitation averaged over the southern part of China. From top to bottom: 1 ensemble, 6, 12, and 100(90) ensembles.

More frequent occurrence of heavy snowfall even under warmer climate condition

Fig. 2 shows the change in snowfall around Japan. Although the surface temperature increases by 4 °C, the heavy snowfall (once in ten years) increases in some mountain areas around the Japan Alps. Multiple ensemble experiments make it possible for us to discuss the change in such rare events.

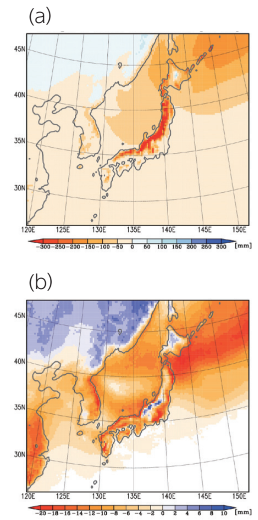


Fig. 2: (a) Future change in total accumulation of snow. (b) Change in heavy snowfall (once in ten years). Units are expressed as water equivalent (mm).

Improved accuracy in projecting disasters caused by typhoons

Moderate sample numbers are indispensable to estimate statistically the change in disasters caused by typhoons. However, only two to three typhoons hit the Japan Islands every year, which makes it difficult to count enough number of samples from only one series of experiment (Fig. 3a). Using d4PDF, we can get an abundant number of samples to be able to discuss typhoon hazards statistically (Fig. 3b).

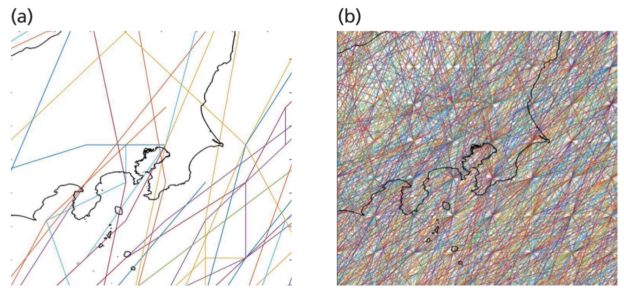


Fig. 3: Tracks of all typhoons simulated in the ensemble experiments. (a) 30-year time-slice experiment. (b) 5400-year simulation of d4PDF.

Contribution to minimize damage from disasters

Extreme phenomena can be estimated statistically using multiple ensemble results. Here we introduce an example of utilizing such information to plan countermeasures to these extreme hazards. Fig. 4 shows the changes in wind speed with a return period of fifty years, and storm surge. These results mainly come from the changes in the strength of tropical depressions. We can use this information to assess the security of oil-rigs, wind power plants, and other facilities situated along the coast.

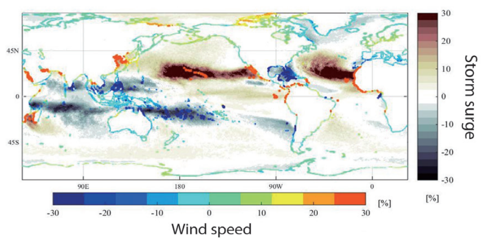


Fig. 4: Future change in wind speed with a return period of fifty years over the ocean, and storm surge height along the coastlines.

Examples of the utilization of SOUSEI's research achievements in Japan and abroad

Contributions to Intergovernmental Panel on Climate Change (IPCC)

Intergovernmental Panel on Climate Change (IPCC), an intergovernmental body for collecting and assessing scientific perceptions on global climate change, publishes assessment reports every 5-7 years. The Fifth Assessment Report (AR5) published in 2013 cites a great number of papers based on results obtained by the models MIROC(-ESM), MRI-AGCM and NICAM whose development has been continued under SOUSEI Project. Also, most of the data submitted from Japan to CMIP5, an international collaborative effort which provided for IPCC a lot of scientific basis for climate change projection, have been produced by those models mentioned above.

Utilization of projection data for JMA's "Global Warming Projection Volume 9"

JMA analyzed the detailed global warming projection data over Japan, and summarized the results in the report, "Global Warming Projection Volume 9". The projection data is produced using the regional climate model, NHRCM05, which dynamically downscaled output from AGCM20, an atmospheric global climate model driven by ensemble sea surface temperature (SST) from several models of CMIP5 (Coupled Model Intercomparison Project Phase 5).
This report is expected to be used actively by local governments for their own adaptation plan to global warming.

An example at Kinan Office of River and National Highway, Kinki Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism

At Kinan Office of River and National Highway, Kinki Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, the data from simulations and pseudo-global warming experiments of Typhoon Vera (1959) (Isewan Typhoon) provided by Theme D of this program have been used to extract hourly precipitation at a high spatial resolution in the Kumanogawa River basin and to compute the amount of river discharge with the use of a runoff model and a dam flood-control model for the entire basin. In addition, from the computed amount of river discharge, the water levels of the river in the downstream management sections have been estimated. At the same time, the challenges and possible improvements of the present timeline are examined. Furthermore, it is expected that the experiment data could be used for examining disaster prevention plans such as evacuation judgement and action by local residents and local governments.

Application of projection data of SOUSEI program for TCC training seminar on global warming projection

In January 2015, JMA's Tokyo Climate Center (TCC) held a training seminar on global warming projection. The seminar focused on enhancing knowledge on global warming and improving skills of invited experts from NHMs (National Meteorological and Hydrological Services) of different countries for their own assessment of climate change.
In the seminar, participants used the projection data produced by SOUSEI program theme C (AGCM20), and prepared reports describing the future climate in their respective countries based on the analysis of these datasets.

Preparing the products of SOUSEI program for Southeast Asian countries

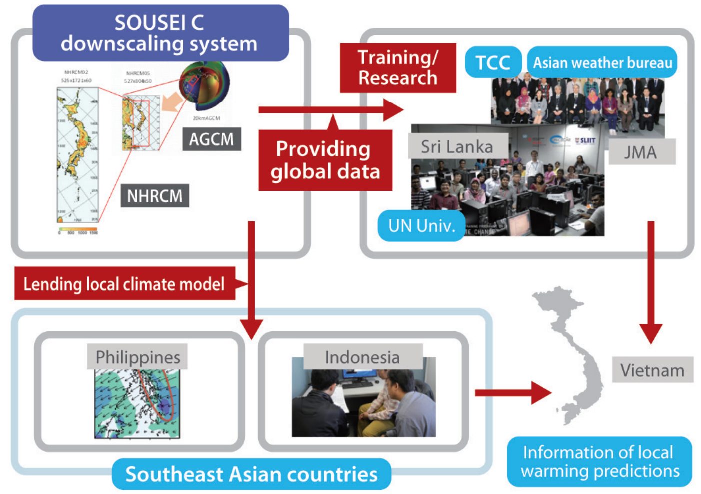
■ Data provision

SOUSEI program theme C has continued joint research with foreign countries by using AGCM-NHRCM downscaling system. It is also a contribution to their capacity development.
Many developing countries in the tropical or sub-tropical region are recognized to be very vulnerable to climate change because the rainfall associated with typhoons and monsoons may become severe in the future warmer climate. However, the design of adaptation plans in these countries may be delayed by the lack of computer resources or the skill in climate projection.


Research presentation scenery

■ Lending local climate model

Until now, some countries typically estimate their future climate by statistically downscaling CMIP5 results. Thus, there are many requests for the results of AGCM20 produced by the SOUSEI program, especially from countries currently without capacity in dynamical downscaling.
In addition, NHRCM is being used in countries that have their own computer resources to estimate their future climate. This procedure originally comes from the goal to increase NHRCM's potential over areas with much warmer climate condition, since Japan is anticipated to be in the semi-tropical regime in the future. However, this also contributes to the capacity building in Southeast Asian countries.
Seventeen researchers from Asian countries have been invited to work together on many joint researches. Results from this collaboration have been published in scientific journals and in climate change assessment reports in some countries.
Furthermore, the research products are part of the CORDEX (Coordinated Regional Downscaling Experiment) project, and contribute to future climate change projection research in Southeast Asia.



Other examples of the utilization of SOUSEI's research achievements

Domestic contribution		
Ministry of Education, Culture, Sports Science and Technology	■ Social Implementation Program on Climate Change Adaptation Technology (SI-CAT) ・Theme 2 (Downscaling) and Model Municipalities (Tottori Pref. and Ibaraki Pref.) ・Theme 3 (Impact Assessments)	◎ Providing projection data for future streamflow changes. ◎ Providing projection data for future global ocean wave changes. ◎ Providing projection data for future storm surge change in Japan.
	■ Data Integration and Analysis System Program	◎ Providing database for Policy Decision making for Future climate change (d4PDF).
Ministry of Land, Infrastructure, Transport and Tourism	■ Panel on Infrastructure Development / Subcommittee on Flood Control for Adaptation for Climate Change	◎ Providing research outcome of future Typhoon changes and the estimation of future changes in precipitation, streamflow, storm surge.
	■ Kinki Regional Development Bureau Basic Development Policy for Shingu River	◎ Providing research outcome of pseudo global warming experiments for Typhoon Vera (T5915).
	■ Co-hosting of the symposium	◎ SOUSEI Research Team D co-hosted with MLIT Water and Disaster Management Bureau.
Ministry of Environment	■ Committee on the Adaption for Climate Change	◎ Providing research outcome on possible changes in the distribution of corals and seaweed forests.
	■ Sectoral Working Group on the Climate Change Impacts: Natural Ecosystem/Water Resources, Natural Disasters, Coastal Disasters/Agriculture, Forestry, Fisheries	◎ Providing research outcome on possible changes in the distribution of corals and seaweed forests.
Ministry of Agriculture, Forestry and Fisheries	■ Hokuriku Regional Agricultural Administration Office: Technical Review Committee for Kuzuryu River Downstream District	◎ Providing research outcome related to high-temperature injury of rice, and water management plan.
The Sasagawa Peace Foundation	■ Research Committee on global warming/ocean acidification	◎ Providing research outcome on possible changes of corals in global warming/ocean acidification.
International contribution		
The Joint WMO=IOC Technical Commission for Oceanography and Marine Meteorology **The Coordinated Ocean Wave Climate Project (COWCLIP)**		◎ Providing projection data on future ocean waves changes.
The National Science and Technology Center for Disaster Reduction (NCDR)		◎ Providing downscaling results of typhoon, and the current/projection data using stochastic typhoon model on future ocean waves changes.
Seoul National University, Republic of Korea		◎ Providing projection data on future changes in ocean waves and storm surge: Utilized for impact assessments for Korean coastal area.
Swansea University, UK.		◎ Providing projection data on future ocean waves changes: Utilized for the projection of future changes in seashores in UK's coastal area.
Marine Scotland Science, UK.		◎ Providing projection data on future seawater temperature: Utilized for joint research on the projection of future marine life distribution with consideration of climate change velocity.