Actionable Science of Climate Change Projection

SENTAN Program Outcomes 2026

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

MEXT-Program for The Advanced Studies of Climate Change Projection(SENTAN)

25 Years of Climate Change Projection Research in Japan

Masahiro Watanabe (Theme 1)

Climate system research has its roots in multiple fields such as meteorology, physical oceanography, and hydrology, and is fundamentally an area in the field of Earth sciences aiming at understanding the formation of and natural variability in the climate system. As global warming became apparent in the late 20th century, the term “climate change” came to include changes in climate attributable to human activities that continuously emit greenhouse gases. Climate change research, as defined here, therefore encompasses a broad theme addressing diverse challenges such as elucidating the mechanisms, detection and attribution, future projections, impact assessments, and adaptation potential for both natural variability and anthropogenic changes. Ultimately, this research is tasked with contributing to the stabilization of the climate system and resolving global warming issues.

For more than 20 years, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) Japan has continuously advanced large national programs for climate change prediction research. These are listed below.

- Human-Nature-Earth Coexistence Project (hereafter, RR2002, FY 2002-2006)
- Innovative Program of Climate Change Projection for the 21st Century (FY 2007-2011)
- Program for Risk Information on Climate Change (hereafter, SOUSEI program, FY 2012-2016)
- Integrated Research Program for Advancing Climate Models (hereafter, TOUGOU program, FY 2017-2021)
- MEXT Program for the Advanced Studies of Climate Change Projection (hereafter, SENTAN Program, FY 2022-2026)

The RR2002 Project was the first national research initiative launched in conjunction with the construction of the Earth Simulator. It has since evolved, updating its specific objectives every five years. Each program emphasizes contributions to the Intergovernmental Panel on Climate Change (IPCC), linking with international research programs to enhance Japan’s research presence. In each program, we have developed and improved numerical models of climate and the Earth system, participated in the Coupled Model Intercomparison Project (CMIP)—the international framework for climate simulations—using the Earth Simulator, and published data for a wide range of uses by the research community and stakeholders. Furthermore, in response to domestic climate change policies such as the Global Warming Countermeasures Plan (2016) and the Climate Change Adaptation Act (2018), the above programs have produced unique Japanese outcomes including the National Climate Change Reports (2020, 2025) and the Climate Change Projection Dataset (2022). Currently, a fifth phase called the SENTAN Program is underway. Leveraging the legacy of the previous four phases (20 years) of the MEXT Climate Change Research Program, a number of universities and research institutions are conducting collaborative research aimed at “establishing actionable climate science for climate change response.”

While nations worldwide strive toward carbon neutrality, the path remains challenging, with atmospheric CO_2 concentrations continuing to rise. Furthermore, extreme weather events such as heat waves, heavy rainfall, droughts and floods are occurring with increasing frequency in various regions, causing damage to society. Concerns are growing that the level of global warming since the preindustrial era will exceed +1.5°C sooner than anticipated owing to the high temperatures experienced worldwide over the past three years. Faced with this reality, climate change projection research is becoming increasingly important.

Advanced Climate Model Development and Future Projection of the Global Climate Towards Contributions to the Next IPCC Report

Hiroaki Tatebe (Theme 1&2), Nagio Hirota (Theme 1), Kentaro Suzuki (Theme1), Tomohiro Hajima (Theme 2)

The Intergovernmental Panel on Climate Change (IPCC) is an international organization that provides comprehensive assessments of the latest scientific knowledge on climate change, and periodically publishes assessment reports that serve as scientific foundations for policy decisions. The findings presented in these reports, including our understanding of past to present climate change and projections of future climate, are based largely on climate simulation research. The SENTAN Program has advanced the development of climate models with the aim of deepening our understanding of Earth's climate system and improving the reliability of future projections, thereby contributing to the next IPCC Assessment Report scheduled for publication at the end of 2029. This article provides an overview of the major achievements obtained in this program.

First, we improved representations of atmospheric, oceanic, and terrestrial processes relevant to climate variability and developed a new physical climate model, MIROC7. Earth's surface temperature is determined by the balance between incoming solar radiation and outgoing infrared radiation, which is influenced by factors such as water vapor, clouds, and greenhouse gases. In MIROC7, we refined the representation of clouds, precipitation, and radiation using state-of-the-art satellite observations, which resulted in substantial improvements in the radiative energy balance compared with the previous model, MIROC6 (Fig.1), as well as enhanced reproducibility of historical surface temperature variations (Fig.2). At the same time, scientific discussions on climate change mitigation require the use of Earth system models (ESMs) that can explicitly link anthropogenic greenhouse gas emissions with carbon uptake by terrestrial and ocean systems—that is, the carbon cycle—and with the resulting climate response. In this program, in addition to establishing a simulation framework optimized for next-generation, accelerator-based supercomputers, we advanced the development of key biogeochemical components, including methane cycling as the second most influential greenhouse gas after CO_2, decomposition of organic matter and the gas emissions from permafrost, marine ecosystem processes that incorporate physiological adaptation to environmental changes, and carbon emissions associated with wildfires. These efforts have enabled more comprehensive representation of the diverse pathways through which human activities and the subsequent greenhouse gas emissions influence the climate system.

Looking ahead to CMIP7, we plan to utilize both the newly developed physical climate model and the ESM to output reliable information on future climate that is directly useful for developing domestic and international adaptation and mitigation strategies, as well as for evaluating the feasibility of emission-reduction targets. Through these contributions, we aim to support and strengthen the next IPCC Assessment Report.

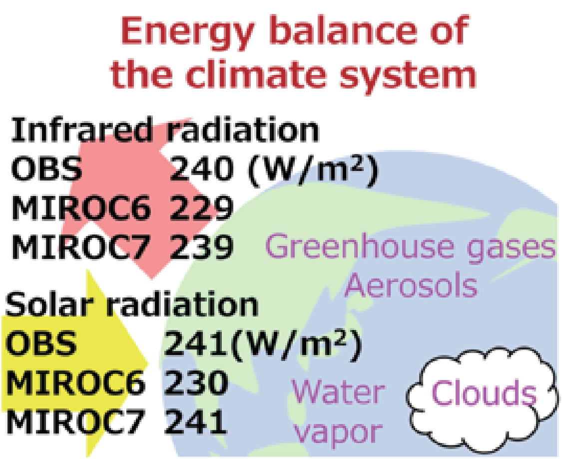

Fig.1 : Schematic of the global radiation budget of Earth's climate system. Solar irradiance and outgoing infrared radiation (W/m^2), as estimated by satellite observations, MIROC6, and MIROC7, are shown.

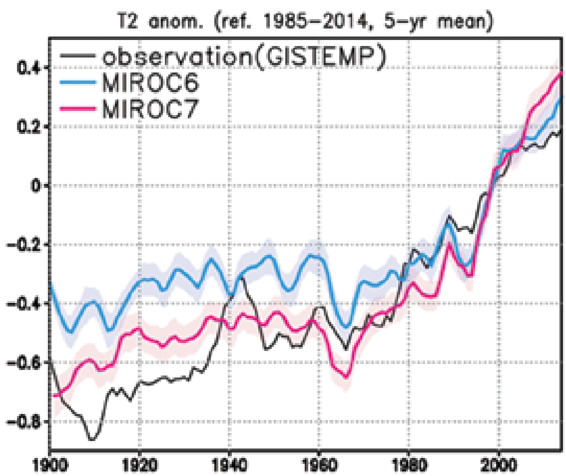

Fig.2 : Timeseries of the global-mean surface air temperature anomalies with respect to the 1985–2014 mean. Black, blue, and red solid lines indicate observations, and MIROC6 and MIROC7 simulations, respectively. Red and blue shading denotes spread of model simulations attributable to natural climate variability. Note that the number of ensemble simulations in each model is three.

High-Resolution Ensemble Climate Projections for Global and Japanese Domains

Hiroaki Kawase (Theme 3), Tomohiro Tanaka (Theme 4)

Future projections of extreme weather based on 5-km large-ensemble simulations over Japan

The database for Policy Decision-making for Future climate change (d4PDF)* has been used not only for research on climate change but also for developing adaptation measures across various fields. However, the 20-km resolution of the regional climate model in d4PDF was insufficient for reproducing detailed local weather conditions in Japan. To address this, past climate, preindustrial climate, and climates corresponding to +2K and +4K warming in d4PDF were dynamically downscaled using a 5-km regional model, producing 732 years of high-resolution data for each climate scenario. Using these datasets, future projections of extreme heavy rainfall, high temperatures, quasi-stationary band-shaped rainfall systems (linear precipitation systems), typhoons, and heavy snowfall were conducted. The 24-h precipitation associated with a 50-year return period was successfully reproduced and increased nationwide across Japan (Fig.3).

Newly implemented high-resolution and time-continuous simulations

The d4PDF was a time-slice experiment designed to target specific levels of global warming. However, to investigate the changes in climate accompanying global warming in greater detail, annual data for the future are required. To address this, we created a seamless, time-continuous, global large-ensemble simulation spanning the past, present, and future (Fig.4a) by combining observed historical ocean variability with six future sea surface temperature (SST) change patterns projected by CMIP6. We refer to this new dataset as d4PDFv2.

By applying regional climate models with 20- and 5-km grid spacing, we generated high-resolution, time-continuous climate projection data with detailed regional information. Examination of future changes in snow depth over Japan, calculated using the 5-km regional climate model, shows that although snow depth is projected to decrease in the future, the rate of decline is particularly large in the near term. Additionally, the spread of the projections widens toward the latter half of the 21st century. This is thought attributable not only to the greater uncertainty in temperature increases in the late 21st century, but also to differences in future SST changes that influence the strength of wintertime pressure patterns, thereby increasing variability in precipitation projections.

Notably, d4PDFv2 is expected to serve as a valuable new source of climate change projection information in the coming years.

* d4PDF: database for Policy Decision-making for Future climate change
Launched in 2015 during the era of the SOUSEI program, the second-generation predecessor of the current program, d4PDF has undergone continuous additions and updates throughout the subsequent TOUGOU and SENTAN programs. This article presents its latest efforts.
Accessible here: https://diasjp.net/ (DIAS: Data Integration and Analysis System)

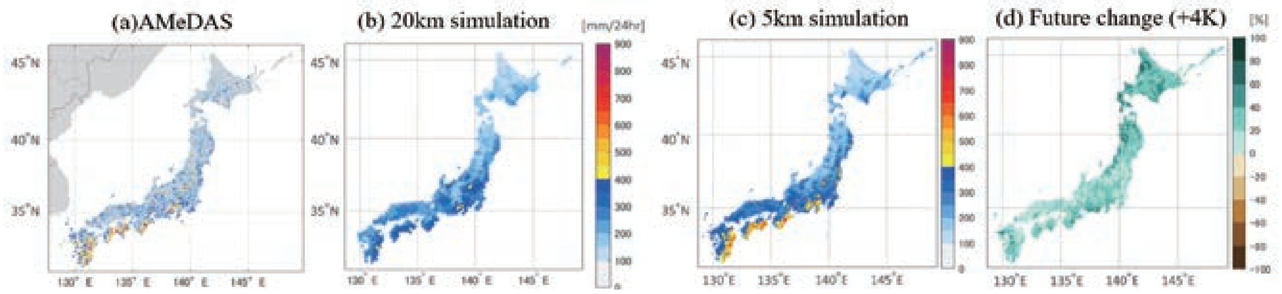

Fig.3 : Reproducibility and future changes in annual maximum 24-h precipitation with a 50-year return period: (a) AMeDAS observations, (b) 20-km and (c) 5-km simulations, and (d) change in 5-km simulation (%).

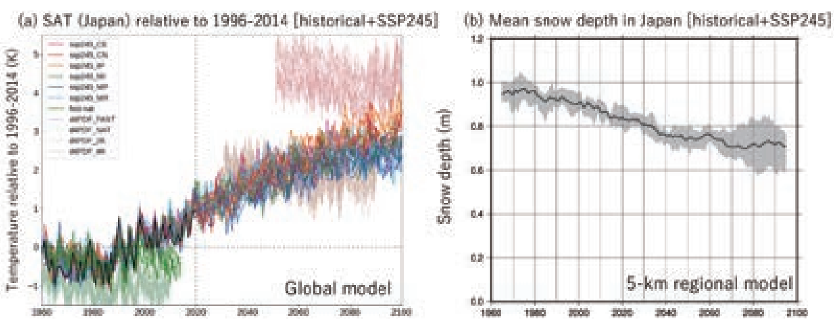

Fig.4 : (a) Air temperature over Japan simulated by the d4PDFv2 global model. Thick lines and thin lines indicate d4PDFv2 and d4PDF, respectively. A black line shows the observations of 15 meteorological stations.
(b) Snow depth over Japan simulated by the d4PDFv2 5-km regional model. Shading denotes the maximum and minimum among the six experiments, and the black line represents the ensemble mean.

The Frontier of Event Attribution Research: Unveiling the Links Between Extreme Events and Climate Change

Yukiko Imada (Theme 1), Hiroaki Kawase (Theme 3), Tomohiro Tanaka (Theme 4)

In recent years, extreme weather events such as heat waves, heavy rainfall, and droughts have occurred with increasing frequency across the globe, drawing attention to their possible connections with ongoing global warming. However, until not long ago, scientists believed it was impossible to demonstrate a causal link between individual extreme events and anthropogenically derived global warming. This is because the primary drivers of extreme weather are the inherent, stochastic “fluctuations” within the atmosphere, meaning that such events can occur even in the absence of global warming. The central challenge, therefore, has been how to disentangle the influence of global warming from natural variability.

To address this challenge, we began working on what is known as Event Attribution (EA) research approximately 15 years ago. This approach constructs two worlds within climate models: one representing the present climate in which global warming is progressing, and another representing a counterfactual world without global warming. By comparing the characteristics of extreme events that arise spontaneously in these two worlds, we can evaluate the influence of global warming.

Extreme events occurring in Japan are affected strongly both by fine-scale topographic features and by large-scale natural variability in the ocean. Therefore, it was essential to use models capable of realistically representing both. Through close collaboration between global and regional climate researchers participating in the SENTSN program, we have succeeded in establishing EA methods tailored specifically to Japan.

Within the SENTAN Program, Research Areas 1 through 4 have been working together toward the goal of achieving “Actionable Event Attribution (EA),” an approach designed to support concrete public actions. Building on the EA methodologies established to date, the program has been advancing these techniques in multiple directions.

By increasing the resolution of climate simulations, EA has become feasible at the prefectural scale in Japan, enabling evaluations of the occurrence probabilities of extreme heat and quasi-stationary convective bands, the “Senjo-kousuitai” (Fig.5). Furthermore, by translating these results into information on hazards such as flooding and storm surges, we are providing insights that help the public better perceive the risks posed by global warming and take informed actions. Another key factor in enhancing public awareness is the timely release of EA information immediately after an extreme event occurs. Because traditional EA methods require large-scale numerical simulations, they are not well suited for rapid analysis. To address this, we have developed a new EA approach that estimates the probability of extreme events using statistical relationships derived from our extensive archive of large-ensemble simulations and observational data (Fig.6).

In total, we have established seven distinct EA methods. By applying these methods, we analyze the influences of global warming and other climatic variabilities on specific extreme events from multiple perspectives.

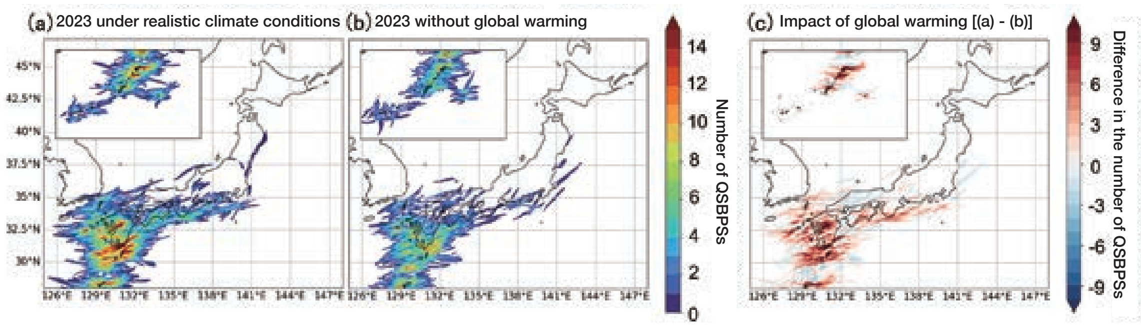

Fig.5 : Number of quasi-stationary band-shaped precipitation systems (QSBPSs) from June 1 to July 10, 2023, under (a) factual 2023 climate conditions including realistic global warming, and (b) counterfactual 2023 climate conditions without global warming. (c) The impact of global warming represented as (a) minus (b).

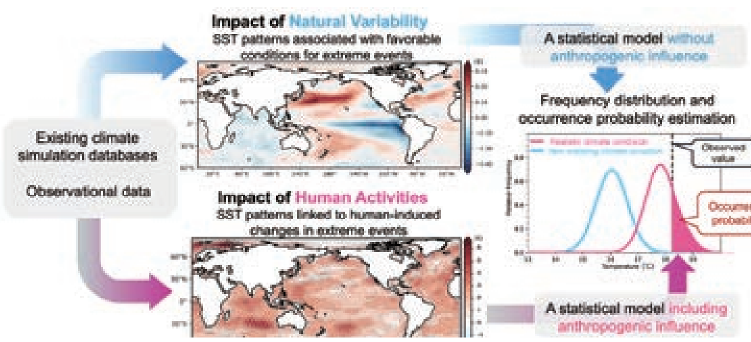

Fig. 6 : Schematic of our statistical method for rapid event attribution.

Extreme Events and Hazard Projections

Takahiro Sayama, Tetsuya Takemi, Toshio Fujimi (all Theme 4)

(1)Strengthening of Extreme Precipitation under Global Warming

As global warming progresses, Japan is shifting toward an environment in which extreme precipitation events occur more frequently and become more intense. Nayak and Takemi (2025) analyzed the characteristics of wet days and extreme precipitation days across Japan by combining observational data with climate model simulations. They confirmed that the intensity of precipitation increases in accordance with the Clausius-Clapeyron relationship, with the amount of atmospheric water vapor rising by approximately 7%-8% for every 1°C increase in temperature. We found that the most intense rainfall does not necessarily occur on the hottest days of the year but rather at slightly lower temperature ranges. This is because, at excessively high temperatures, the atmosphere tends to become drier, and the conditions favorable for heavy rainfall are less easily met. Furthermore, under future climate conditions, the temperature range that favors the occurrence of intense rainfall is projected to shift upward by approximately 2-4°C, suggesting that extreme precipitation events are likely to become even stronger in a warming climate.

(2)Impacts on River Floods Nationwide

Based on the projected increase in extreme precipitation, we assessed the future flood hazard across Japan using high-resolution ensemble climate data (d4PDF 5km) (see also p.4). By applying the Rainfall-Runoff-Inundation (RRI) model across Japan, we found that peak discharges are projected to increase widely, with the increase in some regions greater than 1.4times under warming scenarios. Flood-producing rainfall was classified into typhoon-related and non-typhoon-related events. While typhoons currently account for approximately 70% of major floods, their share decreases in future climates, and non-typhoon floods, such as those during the Baiu and autumn rainy seasons, are projected to increase nationwide. This trend is particularly strong in Hokuriku, northern Tohoku, and the Pacific side to the north of Kanto. At the same time, strong typhoons will remain an important source of flood and storm-surge risk.

(3)Storm-Surge Inundation Risk under Future Population, Asset, and Industry Distribution

We also evaluated future storm-surge inundation risk by incorporating projected changes in population, asset, and industrial distributions. In addition to sea level rise and changes in storm-surge anomalies, future societal conditions were estimated and integrated with a storm-surge inundation model. This enabled comprehensive assessment of future risk from both the hazard and the exposure perspectives. In the Osaka Bay case study, warming-induced increases in storm-surge water levels were found to expand inundation areas. At the same time, some districts are expected to experience reduced exposure owing to population decline. These results indicate that future coastal disaster risk is shaped not only by physical changes in water levels but also by evolving socioeconomic conditions.

References

Nayak and Takemi (2025) https://doi.org/10.1038/s41598-025-22287-6

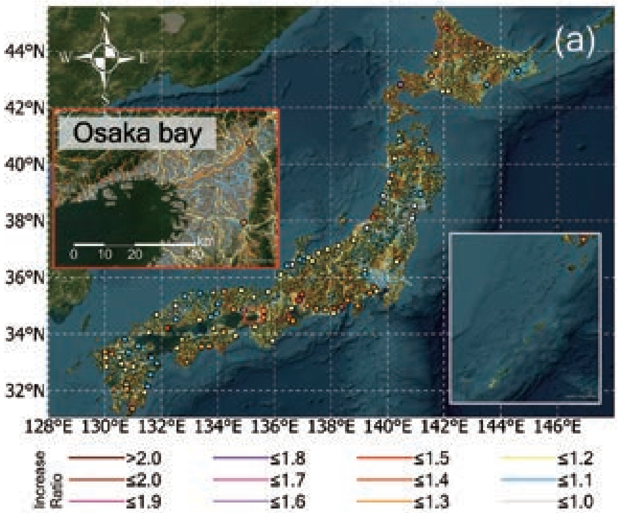

Fig.7 : Estimated increase in 100-year flood discharge under +2°C warming

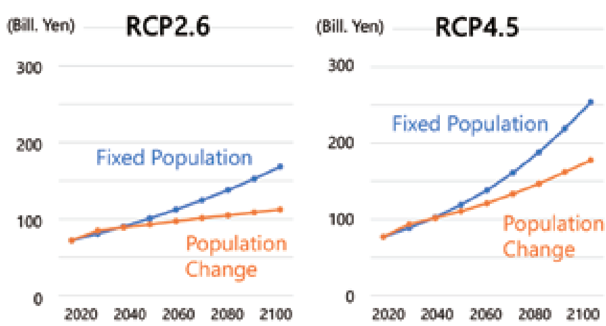

Fig.8 : Expected economic loss from storm-surge inundation in Osaka Bay (blue: population fixed; orange: population change considered)

Projection of the Earth System Including Carbon Cycle

Tomohiro Hajima (Theme 2), Irina Melnikova (Theme 2), Hiroaki Tatebe (Theme 1&2)

To discuss future climate change mitigation, it is essential to understand the relationship between human activities, including anthropogenically derived greenhouse gas emissions, and climate change, and to make projections for a future perspective. The SENTAN Program developed a new ESM and prepared for the CMIP7 Assessment Fast Track, which is closely linked to the IPCC 7th Assessment Report. Furthermore, we tackled new modeling challenges for biogeochemical processes, such as the methane cycle and the decomposition of frozen carbon in permafrost regions, and incorporated them into the ESM (see p.3). Such ESMs allow us to make climate projections based on prescribed anthropogenic CO_2 emissions, not concentration, enabling us to discuss the linkage between emission reduction efforts and climate mitigation. Especially in the CMIP7 phase, we concluded that such an “emission-driven approach” should be adopted widely, and this approach has, in fact, been incorporated into the CMIP7 experimental protocols (Sanderson et al. 2024, Hajima et al. 2025; Fig.9).

ESMs allow us to assess the differences in future climate simulated under various future emission scenarios, exploring available options (see p.8). In particular, ESMs have enabled estimation of the “remaining carbon budget,” which is the cumulative amount of anthropogenic CO_2 emissions that must not be exceeded to meet a specific warming mitigation target. In this program, by combining model results with observational data, we succeeded in reducing the uncertainty of this estimate (Melnikova et al. 2025). We also proactively investigated scientific challenges that will become increasingly important, such as exploring emission pathways for stabilizing specific climate targets and evaluating the potential of Carbon Dioxide Removal (CDR), through international collaboration. Moreover, we coupled our ESM with a data assimilation system, constructing a new prediction system that can account for not only long-term changes in carbon cycle processes but also interannual variation in the carbon cycle, which is caused mainly by internal variability of the climate system. The reconstructed carbon cycle data (Fig.10) and the predictions for the next few years have been utilized in assessment reports annually published by the Global Carbon Project (GCP), and have served as a reference basis in the First Global Stocktake. Our modeling outcomes are now being utilized not only for long-term future projections but also for verifying efforts toward achieving the Paris Agreement goals.

References

Sanderson et al. (2024) https://doi.org/10.5194/gmd-17-8141-2024
Hajima et al. (2025) https://doi.org/10.5194/bg-22-1447-2025
Melnikova et al. (2025) https://doi.org/10.1016/j.oneear.2025.101526

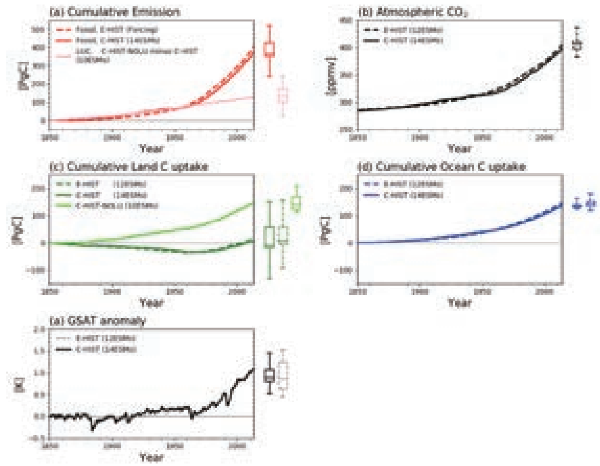

Fig.9 : Multimodel analysis of Earth System Models (12 models). Compared with the concentration-approach (thick lines), the emission-driven approach (dashed lines) reflects the spread of simulated CO_2 concentration (box plot of CO_2 concentration) into the projected climate (Global Surface Air Temperature).

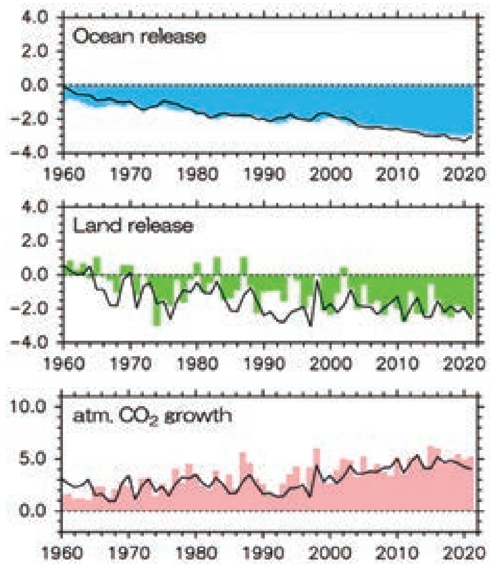

Fig. 10 : Global carbon budget reconstructed by an Earth System Model that is coupled with data assimilation system (PgC/yr).

Tipping Points in the Earth System and Overshoot Scenarios

Tokuta Yokohata, Kazuya Kusahara, Irina Melnikova, Kaoru Tachiiri, Shingo Watanabe (all Theme 2)

The global mean surface air temperature continues to rise, causing various problems for society. A concern in recent years is that a “tipping point” might be exceeded as temperatures continue to rise. A tipping point is defined as a threshold at which elements of the Earth system cause self-perpetuating, abrupt, and irreversible changes (Global Tipping Point Report 2023). Elements of the Earth system at which such changes might occur are sometimes called “tipping elements.”

The Amazon, the world’s largest tropical rainforest, is home to a diverse ecosystem, but there are concerns that the drying caused by climate change might bring about a tipping point at which many plants in this region will die back. In relation to this, we analyzed long-term projections using the latest ESMs and found that most models project that the Amazon rainforest dieback will begin during the 21st century unless efforts are made to stop climate change (Fig.11).

There are various tipping elements in the polar regions, and it has been reported that sea ice in the Arctic and Antarctic oceans, as well as the ice sheets of Greenland and Antarctica, have been declining at an accelerating rate in recent years. In relation to this, we analyzed the mechanism behind the recent rapid decline in Antarctic sea ice using a sea ice-ocean model. We found that the main factor behind the rapid decline in Antarctic sea ice is a strong increase in surface air temperature due to air-ocean interactions at the sea ice edge, and that the surface water warmed through thermodynamic processes thaws the sea ice, resulting in rapid decline in sea ice (Fig.12).

As described above, there are concerns that global warming can cause major changes to the Earth system. To avoid such risks, an “overshoot scenario” (a scenario in which the global mean surface air temperature initially exceeds the Paris target, but the target is achieved subsequently by lowering the temperature) has been considered. To lower Earth’s surface air temperature, it is necessary to reduce the concentration of CO_2 in the atmosphere. While it is not easy to realize such a scenario, it is considered an important scientific topic from various perspectives as a way to mitigate the problem of global warming.

References

Global Tipping Point Report 2023 https://report-2023.global-tipping-points.org/

Melnikova et al. (2025) https://doi.org/10.1038/s43247-025-02606-5

Kusahara and Tatebe (2025) https://doi.org/10.1029/2025GL115256

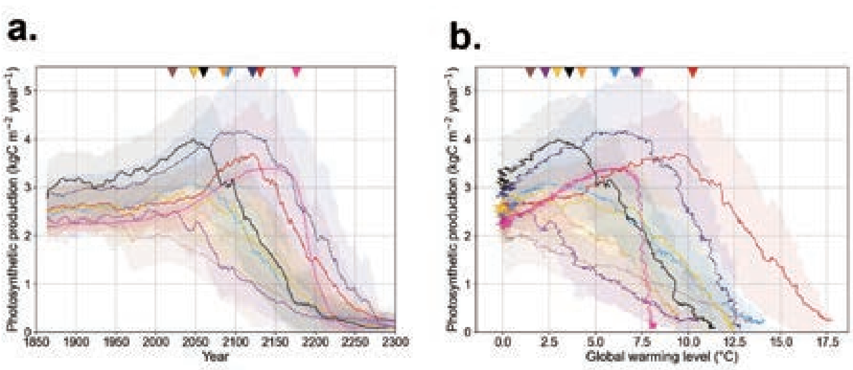

Fig.11 : Changes in photosynthetic absorption in the Amazonian dieback zone from Earth system models. (a) Changes from 1850 to 2300 and (b) changes relative to the global mean surface air temperature change (in °C) from the 1850-1899 average. The colors of the curves indicate the results of different models developed by world climate modeling centers, and the inverted triangles at the top of each panel indicate when Amazonian dieback begins in each model. Figure modified from Melnikova et al. (2025).

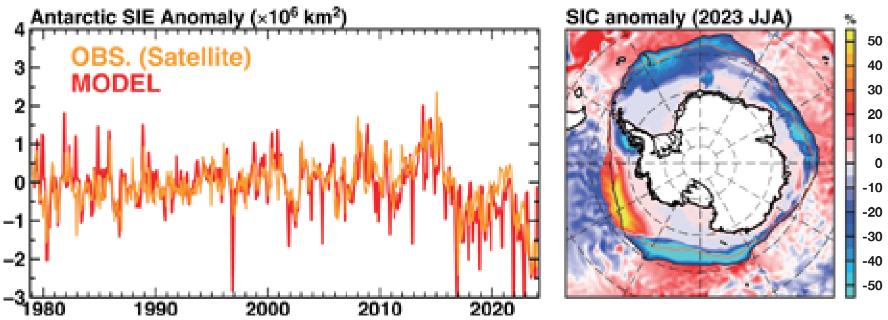

Fig.12 : Changes in sea ice over the Southern Ocean. The left-hand panel shows anomalies of total sea ice extent (SIE) over the Southern Ocean, and the right-hand panel presents model-simulated sea ice concentration (SIC) anomalies in 2023. A pronounced SIE decline is evident after 2016. In the right-hand panel, sea surface temperature (SST) anomalies (warm colors: positive; cool colors: negative) are overlaid north of the ice edge, illustrating the coherent variations between SIC anomalies and SST anomalies. Figure adapted from Kusahara and Tatebe (2025).

Attribution and Projection of Global Climate Change

Yu Kosaka (Theme 1), Tomoo Ogura (Theme 1)

Climate models are indispensable for climate change projections, but projection uncertainties are unavoidable. Combining observational data of past climate change with climate model simulations is useful for ensuring reliability of projections and reducing uncertainties. Here, we introduce two studies conducted in the SENTAN Program.

Driver of Earth's extreme energy uptake in 2022-2023

Earth's energy imbalance (EEI)—the difference between net incoming solar radiation and outgoing infrared radiation—is closely related to global warming. From late 2022 to early 2023, EEI increased markedly (Fig.13), and this surge is key to the record-high global mean temperature and widespread extreme events that occurred in 2023 to 2024.

Our analysis revealed that in CMIP6 multimodel ensemble data, cases exhibiting exceptionally large EEI values tend to be preceded by multiyear La Niña events (Fig.13). It was also found that multiyear La Niña events, compared with single-year La Niña events, lead to larger increase in EEI during their decay phase. These results suggest that the “triple-dip” La Niña event, namely the La Niña conditions that persisted for three consecutive years from 2020 to 2023, was the primary driver of the rapid EEI increase, on top of the human influence. It is suggested that multiyear La Niña events will become more frequent under global warming (Geng et al., 2023), implying that rapid global temperature increases similar to that observed in 2023 to 2024 could occur more frequently in the future.

Reducing uncertainty in extreme precipitation projection

Future changes in climate under various socioeconomic scenarios are projected with numerical simulations using climate models. However, there is large uncertainty, namely intermodel difference, in the simulated results of future climate projections. For example, there is considerable scatter among estimates of by how much heavy rainfall will increase with global warming. Such uncertainty makes it difficult to propose effective countermeasures against climate change. Therefore, understanding and reducing the uncertainty in climate projections matter not only to scientific advancement but also to people’s livelihoods and safety. In the SENTAN Program, we developed a new method for reducing the uncertainty in climate projections by comparing the simulated results with observational data. This method enabled us to constrain the estimates for future extreme precipitation changes more effectively than was possible previously (Fig.14). Consequently, more accurate information will be available to policymakers who are responsible for flood control. We plan to apply this method to other climate variables and further reduce uncertainties, which will help inform policymakers and the next assessment report by the IPCC.

References

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Shiogama et al. (2025) https://doi.org/10.1038/s41467-025-60385-1
Tsuchida et al. (2026) *in press*

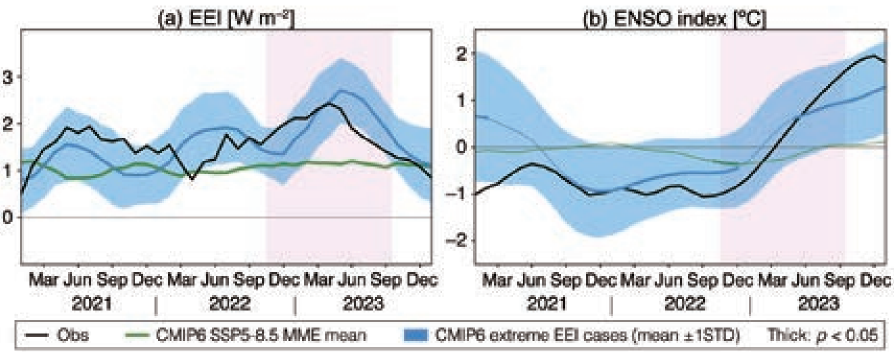

Fig.13 : Variations in (a) EEI and (b) the El Niño-Southern Oscillation index. Black lines indicate observational records from January 2021 to January 2024, and blue lines and shading are based on cases with extreme EEI for the purple-shaded period, subsampled from the CMIP6 high-emission scenario experiment. The mean seasonal cycle has been removed from the EEI. Figures adapted from Tsuchida et al. (2026) with edits.

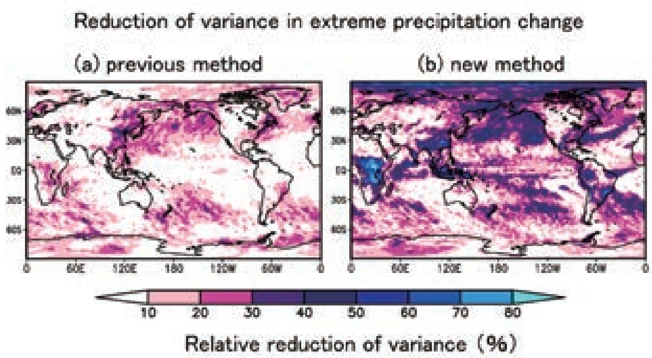

Fig.14 : Reduction of variance in the annual maximum daily precipitation change (2051-2100 minus 1851-1900). Future projections by multiple climate models are constrained by observational data based on (a) previous and (b) new methods. Application of the new method leads to larger reduction of variance compared with the previous one. Figures adapted from Shiogama et al. (2025).

(1) Commitment to IPCC Assessment Reports

Masahiro Watanabe (Theme 1)

The IPCC is an international organization established in 1988 jointly by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). Its purpose is to assess scientific knowledge on climate change and provide a foundation for policy decision making by governments and other stakeholders. The IPCC assessment has been operated with three Working Groups (WGs). Much of the climate change projection research summarized in this compilation has been reflected in the WG1 Report, which focuses on the physical scientific basis of climate change. For each WG, IPCC Assessment Reports are coauthored by over 200 scientists selected from around the world. The reports have been updated every five to eight years, from the First Assessment Report (FAR, published in 1990) to the Sixth Assessment Report (AR6, published in 2021).

For the Japanese climate change research community to contribute to the IPCC, it is important to publish many excellent papers that are cited in Assessment Reports. However, it is also essential to be directly involved in the writing process of the Reports as Lead Authors or Coordinated Lead Authors. In the past WG1 Assessment Reports, 7-10 climate scientists from Japan have consistently participated in the writing process. For the Seventh Assessment Report (AR7, scheduled for publication in 2028), where writing has now commenced, seven individuals have been selected and six of them are members of the SENTAN Program. Additionally, the SENTAN Program has provided members for the IPCC task group on data management, as well as governmental delegates involved in the acceptance of the full report.

The latest Assessment Report (WG1 AR6) cites 13,487 papers in total (Chavelli and Connors 2022). Over half of those are international coauthored papers, highlighting the necessity of advancing climate change research through strong collaboration among the international community. When examining country-based contributions using the number of cited papers as an indicator, the United States stands out prominently. However, contribution by the Japanese research community is also substantial: i.e., 956 papers were cited (7.1% of the fractional contribution) (Fig. 15). This proportion is much larger than the 4.8% share of the total number of research papers published by Japanese scientists across all fields from 2019-2021 (National Institute of Science and Technology Policy 2023). Among the 956 papers from Japan cited in the IPCC Assessment Reports, more than 400 stem from the MEXT climate change research program, according to our own count. AR6 primarily cites papers published since 2013. This includes contributions not only from the SENTAN Program but also from its predecessors. In other words, it underscores the importance of sustained research programs on climate change projections.

The IPCC Assessment Reports have provided the most authoritative scientific evidence for national governments and international climate negotiations such as the Conference of the Parties (COP; see next section). Contributing to these reports not only demonstrates the high level of the climate change research in Japan but also is vital for Japan's role in the global drive toward carbon neutrality. To increase not only the number of papers cited in the reports but also the number of Japanese Lead Authors, continuation of the MEXT climate change research program is highly desirable.

References

Chavelli and Connors (2022) doi: 10.5281/zenodo.7615825
National Institute of Science and Technology Policy (2023) https://www.nistep.go.jp/sti_indicator/2023//RM328_42.html

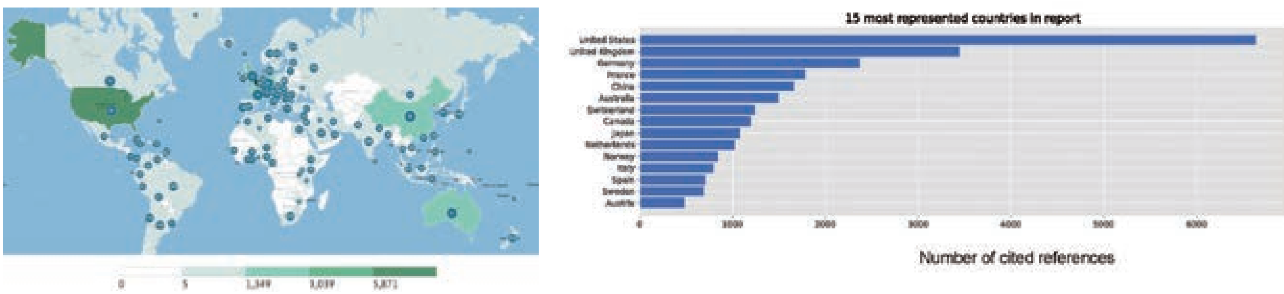

Fig.15 : Country-based number of cited references in the IPCC WGI AR6. Adopted from Chavelli and Connors (2022).

(2) Contributions to the World Climate Research Programme

Michio Kawamiya (Theme 2)

The World Climate Research Programme (WCRP) is an international project for climate science, serving as a driving force for the research community worldwide by setting research perspectives and priorities (WCRP, 2025). WCRP consists of six Lighthouse Activities (LHA), such as “Digital Earths,” which serve as forums for exploring future research directions; six Core Projects (CP), such as CLIVAR, which advance research aligned with these directions; and the “WCRP Academy,” responsible for capacity building. Each component has its own Steering Committee, Working Groups, and other active entities. From the SENTAN Program, a total of six members contribute to the WCRP Steering Committee, two LHAs, and two CPs. CMIP, described in a separate section, is also part of the WCRP activities. Prior to starting CMIP7, nine task teams were established to discuss arrangements for conducting the experiments. From the SENTAN Program, two members joined two of these task teams: one for the unification of output variables and one for the experimental design. Furthermore, in March 2026, the “CMIP Community Workshop” was held in Kyoto, bringing together researchers interested in CMIP from around the world. For this workshop, approximately 15 participants from the SENTAN Program formed a local organizing committee to manage the event, and many participants also gave presentations.

■ References

World Climate Research Programme (WCRP), 2025. WCRP Science and Implementation Plan, First Edition. Publication 01/2025.

Contribution to the International Community

(3) Contributions to the UN Framework Convention on Climate Change

Michio Kawamiya (Theme 2)

The United Nations Framework Convention on Climate Change (UNFCCC) is an international framework aimed at stabilizing greenhouse gas concentrations in the atmosphere, with 198 countries and regions participating. To achieve its objectives, various meetings are held throughout the year, with COP being the largest. In 2022, when the SENTAN Program was launched, JAMSTEC organized a seminar titled “Current status and future perspectives on greenhouse gas emission mitigation and impacts” as a side event at COP27 in Egypt. This seminar introduced the SENTAN Program’s plans and the achievements of its predecessor, the TOUGOU program (Fig.16). Combining on-site and online attendance, the seminar attracted nearly 150 participants. Furthermore, at COP29 in Azerbaijan in 2024, a participant in the SENTAN Program made presentations to lead the discussion at the “Observations for Mitigation” breakout session during the Earth Information Day, demonstrating the presence of the program. Furthermore, in the Global Stocktake, which examines the consistency between the greenhouse gas reduction targets and mitigation goals of various countries, the data papers published annually by the international GCP serve as crucial reference materials. The projection data generated by the ESM developed under the SENTAN Program continues to be adopted in these materials (Friedlingstein, 2023, 2025).

■ References

Friedlingstein, P., et al., Earth Syst. Sci. Data, 15, 5301-5369, https://doi.org/10.5194/essd-15-5301-2023, 2023.

Friedlingstein, P., et al., Earth Syst. Sci. Data, 17, 965-1039, https://doi.org/10.5194/essd-17-965-2025, 2025.

Fig.16 : Scene from the seminar at the COP27 side event. The representative of the SENTAN Program (Area Theme 2) is explaining its purpose.

(1) Providing Climate Change Projection Information to Society

Tosiyuki Nakaegawa (Theme 3)

1) Climate Change Dataset 2022

Under climate projection programs, including the SENTAN Program, we have conducted numerical experiments using climate models to address issues requiring scientific elucidation. Specific examples include dynamical downscaling over the Japan area at 2-km horizontal resolution, large-scale ensemble experiments consisting of 100 members for the present climate and 90 members for the future climate, and 150-year continuous simulations from the mid-20th century to the end of the 21st century.

Efforts regarding adaptations to climate change are progressing against the background of the United Nations Framework Convention on Climate Change (UNFCCC), the Climate Change Adaptation Act in Japan, and the Act on Promotion of Global Warming Countermeasures in Japan. At the national level, the formulation of basic policies for river improvement and plans for land improvement projects is underway. At local government level, the formulation and implementation of Local Climate Change Adaptation Plans are taking place. In the private sector, there is increasing activity in the expansion of ESG investment considering "Environment, Social, and Governance," and in climate-change-related information disclosure based on international sustainability disclosure standards. Climate change projection data are indispensable for these initiatives. Therefore, to promote public and private efforts, we have compiled projection information contributing to climate change adaptation in Japan as the "Climate Change Dataset 2022," which includes The Climate Projection Dataset and Guidance documents (Overview of projection results, and data usage guidance). These resources were developed under the SENTAN program (MEXT and JMA, 2022) and are provided to users in collaboration with the Data Integration and Analysis System (DIAS).

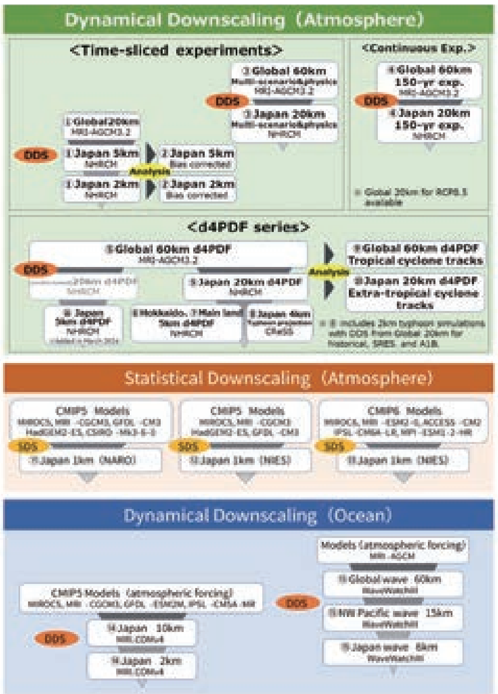

Fig.17 : Schematic of the Climate Projection Dataset 2022 (MEXT and JMA, 2022). Time-slice experiments cover 20-year periods for both past and future climates, while continuous experiments span 1951-2100. The d4PDF series consists of large-scale ensemble experiments.
denotes flow of downscaling from the top to the bottom data; DDS dynamical downscaling; SDS statistical downscaling (including bias correction); and Analysis data analysis (e.g., bias correction, tropical and extratropical cyclone tracks).

2) Climate Change in Japan 2025

In March 2025, MEXT and the Japan Meteorological Agency (JMA) published "Climate Change in Japan 2025: Assessment Report on Observation and Projection of Atmosphere, Land, and Ocean" (MEXT and JMA, 2025) as an updated revised edition for the first time in five years. This report aims to be utilized in various fields for effective promotion of climate change adaptations in Japan. This report reflects new scientific findings and the latest observational data since "Climate Change in Japan 2020," adding mainly the following new information: changes in the frequencies and intensities of extreme heavy rainfall and of extreme high temperatures in future climates, and long-term changes in dissolved oxygen levels indicating the progress of ocean warming. The future climate projection section of this report is based on data developed in climate projection programs under MEXT and included in the "Climate

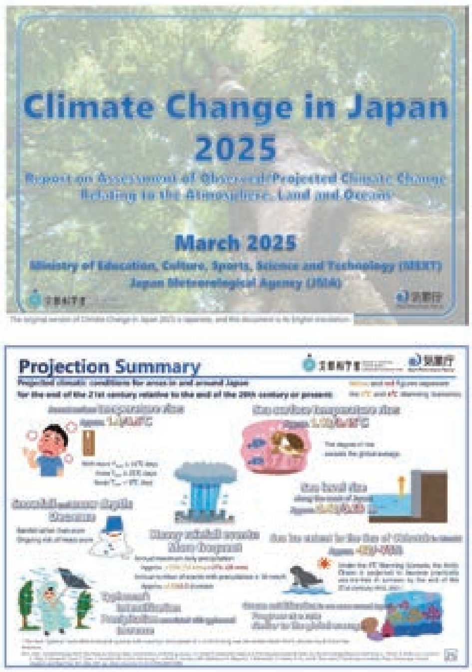

Fig.18 : (Upper) First and (bottom) final pages of Overview of Climate Change in Japan 2025 (MEXT and JMA 2025; https://www.data.jma.go.jp/cpdinfo/ccj/index.html).

Change Dataset 2022." It also incorporates results from EA, which scientifically evaluates how much anthropogenic global warming has influenced the probability or intensity of specific extreme weather events (e.g., heat waves, heavy rainfall) when they occur. Additionally, the latest results obtained from the SENTAN Program are reflected in this report.

■ References

MEXT and JMA (2022) Climate Change Dataset 2022, https://diasjp.net/ds2022/
MEXT and JMA (2025) Climate Change in Japan 2025: Assessment Report on Observation and Projection of Atmosphere, Land, and Ocean https://www.data.jma.go.jp/cpdinfo/ccj/2025/pdf/cc2025_gaiyo_en.pdf

Contribution Within Japan

(2) Social Implementation

Nobuhito Mori (Theme 4)

The climate projection and related findings on flood and wind disaster risks associated with climate change, derived from the SENTAN Program and its predecessor research programs, have been utilized in policies for developing social infrastructure related to flood and wind disasters—such as flood control, urban flooding, Sabo control, and coastal protection—leading to their social implementation (Ishii and Mori, 2019). Several stages exist before the outcomes of climate research are incorporated into flood management policies and implemented socially, such as through infrastructure development. Figure19 illustrates the social implementation process for flood management policy.
To consider updates to regional development plans (climate change adaptation plans), committees and study groups are convened within central government ministries. This requires deliberation on national basic policies and the compilation of recommendations or reports. Researchers, including members of the SENTAN Program, often participate in these committees and study groups as experts, while construction consultants frequently handle data analysis and similar tasks. The committees and study groups discuss the analysis agenda and results for climate change projection data, as well as policies that consider the characteristics of future changes based on current development policies. Therefore, expertise is required not only in climate change projections but also in the specific projects under consideration. As shown in Table 1, numerous flood-related committees within central ministries were discussed during the TOUGOU Program phase in approximately 2020. The SENTAN Program phase now focuses on developing basic plans and improvement plans for regional areas and prefectures (hereafter, referred to as regions) based on national policies. Consequently, in the SENTAN Program, participating researchers serve as members of 35 committees related to regional basic and improvement plans.
Even in the formulation of regional basic and improvement plans, technical committees and subcommittees are established, with researchers from the SENTAN Program participating as experts. In these roles, they introduce and advise on the d4PDF (see p.4), and the climate prediction data and analysis methods developed in the SENTAN Program, thereby playing key roles in connecting the latest research results to societal implementation. Furthermore, while construction consultants handle data analysis within these committees and subcommittees to facilitate active information exchange and discussion between the research program and engineers, Themes 3 and 4 hold annual technical user workshops targeting engineers from construction and environmental consulting firms, non-life insurance companies, and other relevant organizations. These workshops have attracted over 500 participants in total.
To facilitate the application of research outcomes across various fields, including climate risk assessment by private companies such as non-life insurance companies, information exchange is conducted to promote societal implementation of the research results.

■ References

Ishii and Mori (2020) d4PDF: large-ensemble and high-resolution climate simulations for global warming risk assessment. https://doi.org/10.1186/s40645-020-00367-7

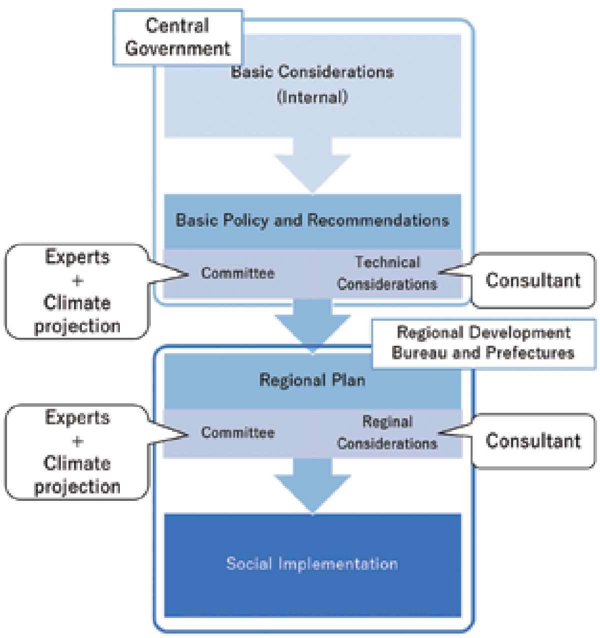

Fig.19 : Process for developing climate change adaptation plans related to water disasters.

Table 1 : Committees related to water disasters

2019	MLIT	Technical Review Committee on Flood Control Planning Considering Climate Change
2020	MAFF/MLIT	Committee on Approaches to Coastal Protection Considering Climate Change
2020	MLIT	Subcommittee on Water Disaster Countermeasures Considering Climate Change
2020	MLIT	Study Group on Urban Flood Countermeasures Considering Climate Change
2020	MLIT	Study Group on Sabo Control Technology Considering Climate Change
2023	MLIT	Consultative Meeting on Physical Risk Assessment in Climate-Related Information Disclosure
2024	MAFF	Study Group on Climate Change Countermeasures in Agricultural and Rural Development
2022-2025	JMA	Consultative Meeting on Climate Change / Evaluation and Review Subcommittee
2022-	Individual states	Hokkaido, Aomori Prefecture, Iwate Prefecture, Ibaraki Prefecture, Chiba Prefecture, Tokyo Metropolis, Kanagawa Prefecture, Shizuoka Prefecture, Aichi Prefecture, Mie Prefecture, Ishikawa Prefecture, Shiga Prefecture, Kyoto Prefecture, Kyoto City, Osaka Prefecture, Nara Prefecture, Hyogo Prefecture, Wakayama Prefecture, Hiroshima Prefecture, Tottori Prefecture, Shimane Prefecture, Tokushima Prefecture, Ehime Prefecture, Kōchi Prefecture, Fukuoka Prefecture, Okinawa Prefecture, Kansai Regional Federation

Contribution Within Japan

(3) Public Symposiums and Other Outreach Events

Yuko Hoshikawa (Theme 2), Michio Kawamiya (Theme 2)

FY	Date	Theme	On-site Venue (Participants)	Total Participants	YouTube Views*
Public Symposium					
2022	January 12, 2023	Climate projection dataset DS2022	Yes (55)	496	748
2023	December 25, 2023	Basics of climate change mechanism (with a focus on students)	No	533	1428
2024	October 20, 2024	Extreme weather: event attribution, impact assessment, and media coverage	Yes (19)	245	1287
2025	August 20, 2025	Climate change and wildfires: local case studies and global satellite observations	No	457	940
Research Reporting Session					
2022	(Not held)				
2023	March 5, 2024	FY2023 Program Research Reporting Session	Yes (27)	260	492
2024	February 13, 2025	FY2024 Program Research Reporting Session	Yes (21)	347	867
2025	January 26, 2026	FY2025 Program Research Reporting Session	Yes (24)	400	Not yet released**

* YouTube Views: Total video views after the event date (excluding views on the day of the event) as of the end of November 2025.
For events where the live stream archive was uploaded without editing, the views generated on the day of the event have been subtracted from the total view count (Symposium FY2022: minus 220 views; FY2024: minus 58 views; Research Reporting Session FY2023: minus 74 views).
**As of Jan 2026

Area Theme 1 Predictive understanding of the Earth system changes based on physical evidence

Principal Investigator: **Masahiro Watanabe** (Professor, Atmosphere and Ocean Research Institute, The University of Tokyo)
Representative organization: Atmosphere and Ocean Research Institute, The University of Tokyo
Partner organizations: Japan Agency for Marine-Earth Science and Technology, National Institute for Environmental Studies, Japan Meteorological Business Support Center

Subject		Representative	
(i)	**Advanced studies for global climate simulations**		
a	Advancing prediction systems for near-term climate-carbon cycle changes	Hiroaki Tatebe	Deputy Director, Japan Agency for Marine-Earth Science and Technology
b	Understanding physical processes of climate change with a synergistic use of global models and satellite observations	Kentaroh Suzuki	Professor, Atmosphere and Ocean Research Institute, The University of Tokyo
c	Understanding and prediction of terrestrial environmental changes	Kei Yoshimura	Professor, Institute of Industrial Science, The University of Tokyo
(ii)	**Attributing and Predicting Earth System Variability**		
a	Understanding global warming levels and reducing uncertainty in climate projections	Tomoo Ogura	Head, National Institute for Environmental Studies
b	Mechanism understanding of past climate changes and future projections	Yu Kosaka	Associate Professor, Research Center for Advanced Science and Technology, The University of Tokyo
c	Deepening and advancement of event attribution studies	Yukiko Imada	Investigator, Japan Meteorological Business Support Center

Area Theme 2 Biogeochemical modeling and climate simulations for carbon budget assessment

Principal Investigator: **Michio Kawamiya** (Director, Japan Agency for Marine-Earth Science and Technology(JAMSTEC)
Concurrently: Professor, WPI-AIMEC, Tohoku University)
Representative organization: Japan Agency for Marine-Earth Science and Technology(JAMSTEC)
Partner organizations: National Institute for Environmental Studies, Central Research Institute of Electric Power Industry

Subject		Representative	
(i)	**A hierarchical approach to advancing Earth system modeling**		
a	Advancing biogeochemical process in Earth system models	Tomohiro Hajima	Deputy Group Leader, Japan Agency for Marine-Earth Science and Technology
b	Integrating multiple evidence with climate model emulators	Junichi Tsutsui	Distinguished Research Scientist, Central Research Institute of Electric Power Industry
(ii)	**Development of an integrated framework for Earth system research**	Hiroaki Tatebe	Deputy Director, Japan Agency for Marine-Earth Science and Technology
(iii)	**Earth-human system interaction and future scenario analysis**		
a	Feedback analysis of Earth-human systems	Kaoru Tachiiri	Group Leader, Japan Agency for Marine-Earth Science and Technology
b	Scenario analysis of Earth-human systems	Tokuta Yokohata	Principal Researcher, National Institute for Environmental Studies
(iv)	**Technical and clerical support for inter-theme cooperation**	Michio Kawamiya	Principal Researcher, Japan Agency for Marine-Earth Science and Technology / Professor, Tohoku University

Area Theme 3 Increasing the sophistication of climate change projections around Japan

Principal Investigator: **Hiroyuki Tsujino** (Principal Investigator, Japan Meteorological Business Support Center)
Representative organization: Japan Meteorological Business Support Center(JMBSC)
Partner organizations: Hokkaido University, Tohoku University, JAMSTEC, Nagoya University

Subject		Representative	
(i)	**Development of projection system and analysis of mechanism for climate change around Japan**	Hiroyuki Tsujino	Principal Investigator, Japan Meteorological Business Support Center
a	Development of projection system for high-resolution global climate change	Ryo Mizuta	Investigator, Japan Meteorological Business Support Center
b	Development of projection system for regional climate and land surface in Japan	Hiroaki Kawase	Investigator, Japan Meteorological Business Support Center
c	Development of projection system for ocean change around Japan	Hideyuki Nakano Yoichi Ishikawa	Investigator, Japan Meteorological Business Support Center Director-General, Japan Agency for Marine-Earth Science and Technology
d	Analysis of mechanism for climate change around Japan	Hirokazu Endo	Investigator, Japan Meteorological Business Support Center
(ii)	**Creating climate change projection information and elucidating extreme event mechanisms for promoting regional and basin scale adaptation measures**	Tomohito Yamada	Professor, Faculty of Engineering, Hokkaido University
a	Developing high-resolution data sets and prediction method using dynamical and statistical methods	Tomohito Yamada Kazuhisa Tsuboki	Professor, Faculty of Engineering, Hokkaido University Professor, Nagoya University
b	Analysis of climate and weather factors causing recent extreme weather events	Hiroaki Kawase	Investigator, Japan Meteorological Business Support Center
c	Elucidating the mechanism of extreme events considering the risk increase and maximum magnitude at the regional and basin scale	Takeshi Yamazaki	Professor, Graduate School of Science, Tohoku University
(iii)	**Creation of high-accuracy climate projection datasets for vulnerable regions in the world**	Akihiko Murata	Investigator, Japan Meteorological Business Support Center
	Promotion of projection products use and user communication	Toshiyuki Nakaegawa	Investigator, Japan Meteorological Business Support Center

Area Theme 4 Development of an integrated hazard projection model

Principal Investigator:**Nobuhito Mori** (Professor, Disaster Prevention Research Institute, Kyoto University)
Representative organization: Kyoto University
Partner organizations: The University of Tokyo, Hokkaido University, Public Works Research Institute ICHARM, National Agriculture and Food Research Organization

Subject		Representative	
(i)	**Integrated hazard modelling and nationwide future projections**	Takahiro Sayama	Professor, Disaster Prevention Research Institute, Kyoto University
(ii)	**Elaborate hazard model development and hazard mechanism elucidation**	Kenji Tanaka	Professor, Disaster Prevention Research Institute, Kyoto University
a	Hazard assessments of wind hazard, water-related disasters and water resources	Kenji Tanaka	Professor, Disaster Prevention Research Institute, Kyoto University
b	Hazard assessments of forests and coastal ecosystems	Masahiko Fujii	Professor, Atmosphere and Ocean Research Institute, The University of Tokyo
(iii)	**Quantification of climate change factors in extreme hazards**	Tetsuya Takemi	Professor, Disaster Prevention Research Institute, Kyoto University
(iv)	**International cooperation for hazard and risk assessments in the Asia-Pacific region**	Yasuto Tachikawa	Professor, Graduate School of Engineering, Kyoto University
(v)	**Flexible adaptation strategies to the future changes in hazard and society**	Toshio Fujimi	Associate Professor, Disaster Prevention Research Institute, Kyoto University

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Toward Further Advancement of Climate Change Projection Research in Japan

Yukiko Imada (Theme 1), Hiroaki Tatebe (Theme 1&2),
Hiroyuki Tsujino (Theme 3), Nobuhito Mori (Theme 4)

In 2024, both the global mean surface air temperature and the atmospheric CO_2 concentration reached the highest levels ever observed, and the temperature increase relative to the preindustrial period temporarily exceeded the Paris Agreement's 1.5°C threshold. Anthropogenic CO_2 emissions also continue to rise, making the achievement of temperature-stabilization targets increasingly difficult. Moreover, extreme events that exert substantial impacts on society have become more prominent, growing the demands for highly reliable climate information that can support both adaptation measures—such as disaster risk reduction and water resource management—and mitigation strategies. Under this background, and building upon the achievements obtained through the present SENTAN Program, the reliability of near-future climate predictions covering the next several years to several decades must first be further enhanced, and their potential applications broadened. In particular, to prepare for unprecedented extreme events that are increasing in frequency of occurrence both nationally and globally, we will advance research approaches in which traditional climate change projections/predictions are integrated with the attribution techniques for extreme events that have been developed to date. This approach will enable more accurate prediction of changes in the occurrence frequency and intensity of extreme events. To elucidate coherent mechanisms that link global climate change with regional-scale extremes, and to provide highly reliable risk information, improvements of the existing system for near-term climate–carbon cycle predictions are required. Moreover, broader and more effective utilization of high-resolution, large-ensemble future projection datasets, such as d4PDF, and the further expansion of these datasets will be pursued. Furthermore, by incorporating rapidly advancing AI-based weather prediction technologies with conventional dynamical prediction models, we will develop new high-quality reference datasets for Japan. Through these efforts, we will accelerate integrated hazard assessments based on probabilistic prediction information, an approach becoming increasingly feasible as the SENTAN Program progresses, and contribute to the development of concrete adaptation measures for extreme events confronting Japan, including heavy rainfall and snowfall, storm surges, and abnormal sea level variations. Concurrently with research supporting adaptation to climate changes, we will also advance prediction studies that assess the effectiveness of emission-reduction measures and evaluate the validity of mitigation strategies. These efforts aim to deepen our understanding of anthropogenic and natural carbon sinks that govern the recovery and stabilization of the climate system, thereby generating insights useful for designing feasible, low-side-effect mitigation scenarios. By integrating these expected achievements, we aim to drive innovation in climate prediction science and build the foundation for a next-generation prediction ecosystem capable of assessing a broader range of targets, such as health risks, losses in primary industries, and financial impacts under the effects of climate change that have not been considered sufficiently to date. By expanding research collaborations, new frameworks for cooperation among climate scientists, experts of other research fields, and decision makers can be established, thereby accelerating the creation and delivery of knowledge directly supporting societal adaptation and mitigation strategies.

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

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