Consideration of Uncertainties in this Projection

How is the possible range of changes calculated?

Why do we need multiple scenarios and cases of climate projection?

Climate change projections necessarily involve uncertainties due to various factors. Therefore, to use climate projections for effective decision making, it is necessary to properly comprehend and interpret such uncertainties.

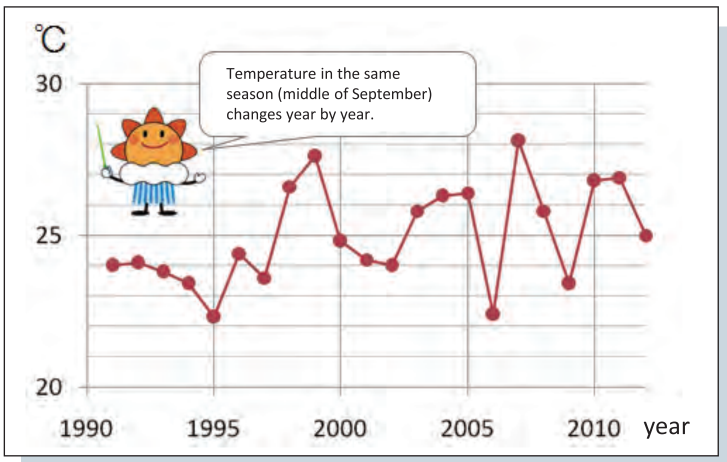
The main uncertainties associated with climate change projections are as follows:

1 Uncertainties associated with natural variations

Even without any influence from human activities, climate tends to change constantly due to natural factors. Among natural fluctuations, we can cite short-term phenomena such as daily weather changes and also longer term phenomena such as heat waves and cooler-than-normal summers as contributing to forming different year-to-year characteristics. Furthermore, among longer-term fluctuations, there are also those that have gradual effects over several years or more than 10 years.

Because of the existence of such longer-term natural fluctuations, it is not appropriate to examine trends of temperature or precipitation over just one year and discuss the possibility of the existence of a global warming trend based on the results of such short-term examinations, because we cannot distinguish if a natural fluctuation occurs by accident or is due to a change in the amount of greenhouse gas emissions.

Accordingly, it is normal when simulating climate change projections to see whether there is in fact a long-term change occurring, after removing the influences of natural fluctuations, and by taking statistics of average values on a long-term basis (20-30 years)[22].



Tnterannual fluctuations of temperature in Fukuoka around the middle of September (from 11th to 20th) during the period from 1991 to 2012

Source: Japan Meteorological Agency

2 Uncertainties associated with future greenhouse gas emissions

Future conditions for climate change projections are considered by estimating the amount of greenhouse gas emissions under certain assumptions. Although the amount of future GHG emissions depends on changes of population, economic development, policies, technological advancement, etc., it is difficult to present unified, high-accuracy projections on a long-term basis for each of these conditions. That is why we need to assume multiple scenarios that are considered to be reasonable from a socio-scientific viewpoint, and assess their individual impacts on climate, using climate-change models, on the supposition that they are realized.

22----- There is also a possibility of statistical uncertainty when the period covered by statistics is limited.

3 Uncertainties associated with climate-change models

Climate-change models are computer programs that express the scientific understanding of global climate systems including atmosphere, oceans, and land in calculable formulae and process them using computers. However, because actual climate systems are extremely complex and they are not yet fully understood, models are not capable of reproducing actual systems completely, although there is a possibility that gaps between reality and programs will be narrowed in the future with advances of scientific knowledge.

Furthermore, when we build simulation programs based on numerical formulae, there are still constraints in the sense that current computers are not capable of handling all of the required calculations, and this limits available spatial resolution (grid size), although this constraint may also be reduced when the capacity of computers is improved in the future.

In this projection, we perform projections based on multiple scenarios together with multiple cases to take into account various uncertainties where possible, assuming that such uncertainties actually exist, and analyze the calculation results.

Picture: Snow cover in Niseko, Hokkaido
Particularly in the region with a lot of snow, future changes of snow depth and snowfall are thought to make an impact on its leisure industry and its culture. However, there is a high degree of model uncertainty associated with the bias error vis-à-vis the present climate. Therefore, we need to be cautious when using it.

Treatment of uncertainties in this projection

Although we take into consideration a range of uncertainties associated with projections by setting multiple cases in this study, there are still uncertainties not covered by this study due to constraints on the number of cases we can handle. It should be noted, in particular, that our case-setting does not consider the entire range of uncertainties presented by other studies including the WGI Report for the Fifth Assessment Report (2013) of IPCC.

Uncertainties are treated in this study in the following manner.

1 Uncertainties associated with natural fluctuations

Regarding uncertainties associated with natural fluctuations, we assessed the average tendency of projections over 20 years as our target, and considered the range of uncertainties by quantitatively evaluating the magnitude of interannual fluctuations.

However, because the natural fluctuation component of the present climate is used when setting sea surface temperature for future climates, there is a possibility that some natural fluctuations that could occur in the future are underestimated.

2 Uncertainties associated with future greenhouse gas emissions

In this study, we use four scenarios (i.e. RCP2.6, 4.5, 6.0, and 8.5) out of a larger number of representative concentration pathway (RCP) scenarios used in the First Working Group Report (2013) for the Fifth Assessment Report (AR5) of IPCC, and make projections based on the conditions of these four scenarios. Uncertainty in this respect means that we cannot know which scenario (or any other scenario) will become a reality. However, there still remains room for us to select a specific scenario through decision-making in the future.

3 Uncertainties associated with climate models

In this study, we take into consideration uncertainties associated with climate-change models by performing projections based on a number of cumulus convection schemes (TS, AS, and KF) and sea surface temperatures (SST1, SST2, and SST3) in the global climate model. Generally, there are a large number of possible parameters and options associated with the methods. Uncertainty here means that we do not know the most suitable settings for each selection.

The cumulus scheme is an option related to the generation and disappearance of small spatial-scale cumulus clouds, and setting sea surface temperature is an option for uncertainties associated with atmospheric-oceanic models, but there should certainly exist other uncertainties in addition to these two.

Because it is temporally not possible for us to conduct a vast range of simulations by considering all possible combinations of uncertainties, we pay special attention to changes associated with precipitation, which is considered to be important for climate change in Japan based on our meteorological knowledge and experience, and select two items (i.e. cumulus convection scheme and sea surface temperature)[23] . To focus only on spatial patterns of the magnitude of temperature increases when setting magnitudes of sea surface temperatures in predictive calculations, we standardize them so that the magnitudes of average temperature increase become the same for all three patterns. As a result, differences in the sensitivity of temperature increase (i.e. climate sensitivity), which is considered in IPCC AR5, are not taken into account in our study.

23----- This setting is the same as that in "Climate Change Risk Information Creation Program of MEXT: Study Area C: Basic Technology Development for Climate Change Risk Information"

Method of expressing uncertainties in this projection ~ statistical processing

In this study, we try to statistically express a range of uncertainties using calculation results for multiple cases. Different types of uncertainty are considered in the following manner.

1 Uncertainties associated with natural fluctuations

As regards uncertainties associated with natural fluctuations, the variance of interannual fluctuations are taken into consideration. Uncertainties in a limited statistical period using a bootstrap method[24] are also considered.

2 Uncertainties associated with future greenhouse gas (GHG) emissions

Although we use projection results under four GHG emission scenarios, we do not indicate a range of uncertainties by combining the results of different scenarios. That is because this uncertainty shows various options for future measures to reduce GHG emissions, and it is difficult to consider the degree of certainty when handling the results of climate change projections.

3 Uncertainties associated with climate models

A range of uncertainties is estimated by combining the results of multiple cases. Although there are nine results for the RCP8.5 scenario (three for cumulus convection schemes, three for sea surface temperatures) and three results for comparisons among different scenarios (three for sea surface temperature), we performed analyses by assuming that the likelihood of all cases is the same. As variations among cases increase (e.g. temperature is slightly higher, precipitation is larger in specific seasons, etc.), the range of uncertainties increases.

Summarizing the above, this study assesses uncertainties of the projection as a whole, by combining the following three uncertainties[25] .

- Uncertainties due to interannual fluctuations (corresponding to ① above.)
- Uncertainties due to adapting average values for a period of 20 years (corresponding to ①above)
- Uncertainties due to differences in tendencies among plural cases (corresponding to ③ above)

It is necessary to note that the following assumptions are made.

- It is assumed that results for different years and for different cases are statist cally independent.
- Sample mean and sample variance are used as the approximate values of the population mean and the population variance, respectively.
- The likelihood of all cases is assumed to be the same[26] .

24----- Bootstrap method: This method creates a large number of samples by repeating many random extractions (e.g. 10,000 times) (in which replacement is permitted) from a finite set of data (e.g. yearly values for 20 years) at a certain pre-set number of times, such as the same number as the number of data in question (e.g. 20 times) and analyzing the characteristics of the population, using such samples.
25----- 1.64 times the square root of the sum of the different types of uncertainty corresponds to the vertical lines (error bars) in the graphs on pages 4, 7, 8, and 14.
26----- In the existing literature, there are procedures that put more weight on model(s) that can reproduce observed data of the present climate with higher accuracy.

Reproducibility of Present Climate

To what extent can climate models reproduce actual climate?

We carried out the calculations for the present climate below, using the climate models, and compared the results with observed climate conditions. This verification is necessary and important, because the fact that we are able to reproduce present climate using models with a high degree of accuracy can be a major premise for us to discuss future climate changes by using our projection calculations.

We compared observation values by AMeDAS[27] with the projectied present climate, and assessed the reproducibility of the model and parameters we used for our study. At that time, we assessed the magnitude of bias (deviation from observed values) based on the following standard and verified the extent to which models can reproduce present climate[28] .

Description standard of bias

Standard	Description in this study
Cases where the regional average of systematic error is above the observation-value standard deviation between points	There is positive (or negative) bias
Cases below the standard deviation	There is no obvious bias Positive (or negative) bias is observed, and dispersion of bias is also large

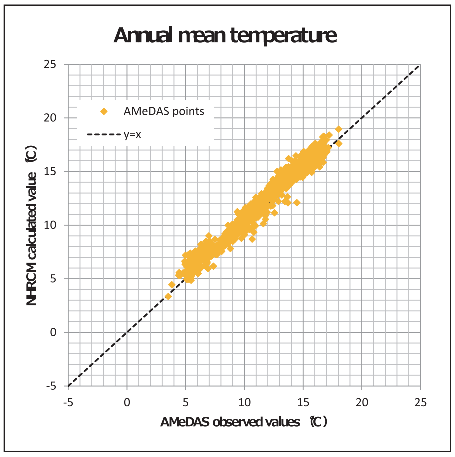
Reproducibility of temperature

Regarding temperature, there is no obvious bias (except for the Okinawa/Amamiwhere there are only a few observation points and it is difficult to assess the degree of bias appropriately), and it can be said that observation values are, by and large, reproduced.

When we look at the correlation diagram of annual mean temperatures over 20 years, we can find the same trend.

(Unit：℃)

	Annual	Spring	Summer	Autumn	Winter
National Average	0.54 (3.64)	0.38 (3.78)	1.24 (2.94)	0.52 (3.43)	0.01 (4.58)
NJ	0.28 (2.19)	-0.02 (2.08)	1.45 (1.83)	0.33 (2.05)	-0.66 (3.05)
NP	0.68 (2.44)	0.44 (2.45)	2.21 (2.14)	0.54 (2.13)	-0.50 (3.40)
EJ	0.62 (1.01)	0.48 (1.05)	0.99 (0.69)	0.60 (1.07)	0.40 (1.38)
EP	0.32 (2.51)	0.16 (2.51)	0.95 (1.99)	0.31 (2.62)	-0.17 (3.11)
WJ	0.80 (1.42)	0.72 (1.41)	0.86 (1.12)	0.88 (1.57)	0.75 (1.76)
WP	0.68 (1.87)	0.66 (1.87)	0.71 (1.30)	0.63 (2.04)	0.70 (2.44)
OA	0.58 (0.36)	0.49 (0.46)	0.51 (0.28)	0.80 (0.31)	0.54 (0.50)



Left: Comparison of reproducibility of annual mean temperature by region
This Table shows regional averages of bias by region, which were obtained by subtracting the actual observation values from the values obtained from the Regional Climate Model (RCM). Values in parentheses are standard deviations between points. Unit is ℃. In the case where there is a positive (negative) bias (i.e. the absolute value of bias is above standard deviation), the relevant columns are painted in orange (blue).
Right: Correlation diagram between AMeDAS observation values and NHRCM calculation values (annual mean temperature over 20 years)

■ Bias Correction

Regarding the reproducibility of present climate conditions, it can be said that we are able to reproduce observation results of temperature fairly accurately. Therefore, with respect to annual average temperature (daily average, daily maximum temperature, and daily minimum temperature), we used values without making any corrections. However, when we handle changes to statistical values with thresholds, such as the number of hot days, the results could be significantly inaccurate if the occurrence frequency distribution deviates between observation values and climate model output values. Therefore, we set the necessary corrections to bias when we calculated the numbers of hot days and frost days.

27----- AMeDAS is short for Automated Meteorological Data Acquisition System
28----- In this study, calculation results of the present climate based on YS scheme are shown.

We found that there is a larger bias for precipitation than temperature, by looking at results reproducing present climate conditions. Therefore, we decided to use values after bias corrections for all model calculation results of precipitation when using them for comparison purposes.

Because bias corrections are performed by comparing the model calculation results of the present climate with data observed by AMeDAS, calculation results after bias corrections are treated as values for AMeDAS observation points used for correction purposes. Therefore, if you look at the charts showing the number of hot days or changes in precipitation, you will see an aggregation of colored dots, not continuously colored areas.

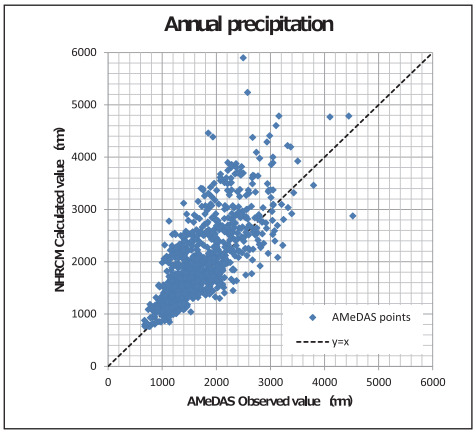
Because we have not made any bias corrections concerning snow depth and snowfall in this report, we need to be cautious when using the projection results.

Reproducibility of precipitation

As regards precipitation, a positive bias is clear nationwide, and in the Sea of Japan side of eastern Japan there is a statistically significant bias for annual precipitation. When we look at the correlation diagram of precipitation over 20 years, we can see that the dots are dispersed more in the upper direction (namely, in the direction where calculated values are larger).

(Unit：mm)

	Annual	Spring	Summer	Autumn	Winter
National Average	265.9 (577.1)	51.6 (161.4)	70.0 (259.2)	9.0 (135.8)	135.7 (191.9)
NJ	64.1 (432.5)	53.2 (90.5)	-72.5 (120.8)	-44.1 (107.8)	127.2 (160.2)
NP	99.2 (307.3)	32.5 (72.9)	-81.7 (110.0)	10.0 (91.7)	139.7 (77.6)
EJ	193.9 (407.5)	93.8 (72.8)	156.1 (80.6)	-65.7 (112.4)	8.7 (200.7)
EP	549.7 (494.0)	69.8 (143.1)	215.5 (182.9)	70.4 (135.8)	194.3 (104.4)
WJ	21.5 (285.5)	31.7 (86.1)	-57.9 (223.3)	-54.0 (77.6)	102.6 (140.8)
WP	432.3 (692.6)	50.3 (188.4)	200.7 (335.9)	43.6 (153.8)	138.3 (85.6)
OA	227.1 (431.2)	-61.5 (90.5)	305.1 (130.8)	4.6 (128.7)	-20.5 (92.2)



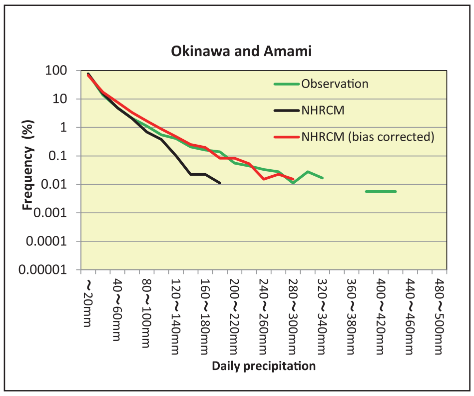
Left: Comparison of reproducibility of annual/seasonal precipitation by region (before bias correction)
This table shows regional averages of bias by region, obtained by subtracting the actual observation values from the values obtained from the Regional Climate Model (RCM). Values in parentheses are standard deviations between points. Unit is mm. In the case where there is a positive (negative) bias (i.e. the absolute value of bias is above the standard deviation), the relevant columns are painted in blue (orange).
Right: Correlation diagram between AMeDAS observation values and NHRCM Model values (average annual precipitation over 20 years)

Therefore, we applied bias corrections to daily precipitation.

As a result, there is no longer clear bias, and the shape of the frequency distribution of precipitation is similar for observation and calculation values.

(Unit：mm)

	Annual	Spring	Summer	Autumn	Winter
National Average	-35.5 (577.1)	-0.3 (161.4)	-8.1 (259.2)	4.9 (135.8)	-31.7 (191.9)
NJ	-16.9 (432.5)	-2.6 (90.5)	14.1 (120.8)	2.7 (107.8)	-31.4 (160.2)
NP	4.5 (307.3)	0.9 (72.9)	20.2 (110.0)	2.8 (91.7)	-18.2 (77.6)
EJ	-97.5 (407.5)	-6.6 (72.8)	-11.4 (80.6)	1.1 (112.4)	-81.6 (200.7)
EP	-50.5 (494.0)	-2.0 (143.1)	-6.1 (182.9)	4.9 (135.8)	-46.9 (104.4)
WJ	-25.1 (285.5)	2.1 (86.1)	-12.8 (223.3)	9.7 (77.6)	-23.2 (140.8)
WP	-52.4 (692.6)	3.0 (188.4)	-43.9 (335.9)	6.9 (153.8)	-18.1 (85.6)
OA	-172.3 (431.2)	-5.2 (90.5)	-167.0 (130.8)	0.2 (128.7)	0.3 (92.2)



Left:Comparison of reproducibility of annual/seasonal precipitation by region (after bias correction)
This table shows regional averages of bias by region, obtained by subtracting the actual observation values from the values obtained from the Regional Climate Model (RCM). Values in parentheses are standard deviations between points. Unit is mm.in the case where there is a blue(orange). bias (i.e. the absolute value of bias is above the standard deviation), the relevant columns are painted in positive(negative)
Right: Comparison of reproducibility of occurrence frequency distribution of daily precipitation (Example: Okinawa/Amami)

Reproducibility of snow depth and snowfall

Regarding annual maximum snow depth, there was a positive bias in the Pacific side of eastern Japan.

Regarding snowfall, there was a positive bias nationwide. Based on its reproducibility, it is necessary to refer to projection results. Although these biases should be corrected to use these data, any bias correction methods are not applied in this puclication, for now there are no concrete reproductibity validation methods or bias correction method. Therefore, we need to be cautious when using it.

Instructions on Using the Products of this Projction

Where are the results of climate projections stored and maintained?

To widely use the results of examinations based on the climate projections for impact assessments of global warming in the future, it is important to open data to the public, while taking into account the convenience of users.

As a result, data from the results of our climate projections are stored within the Data Integration and Analysis System (DIAS) of the Program for Integration and Fusion of Earth Environment and Observation Information operated by Tokyo University, which is entrusted by the Ministry of Education, Culture, Sports, Science and Technology, and they are open to the public through the system[29] .

Users can access various data registered and stored within DIAS by registering their names. To promote the use of data, a guide, "Data Management Manual for Climate Change Projection Results" is also available.

■ Data preserved and available from DIAS

1 Regional Climate Projection Data

The dataset is composed of output values from the Regional Climate Projection Model (MRI-NHRCM20) of Meteorological Research Institute, Japan Meteorological Agency, and the data obtained by statistically processing the above output values. The climate projection and reproducibility of present climate conditions presented in this publication were calculated based on data from the data set.

The file formats contained in the data set are as follows:

- Processed data: Data items expected to be used for impact assessments etc. are provided in NetCDF format.
- Bias correction data: Data to which bias corrections were applied are provided in Text format.
- Raw data: Direct, unprocessed output data from MRI-NHRCM20 Model are also available for further detailed analyses.

2 Global Climate Projection Data

This dataset is composed of output values from the Global Climate Projection Model (MRI-AGCM3.2H) of Meteorological Research Institute, Japan Meteorological Agency. The file format contained in this data set provides only unprocessed data (raw data) directly outputted from the MRI-AGCM3.2H Model30 .

When conducting a detailed examination of climate change impact assessments covering Japan and its vicinity, for instance, it is recommended to use regional climate change projection data (data set of MRI-NHRCM20), which are the result of detailed analyses using this data set as boundary conditions (because the spatial resolution is small, the data reproduce more detailed climatic phenomena).

29----- The official names of the data are "Global Climate Change Projection Data by MOEJ (in cooperation with JMA)" and "Regional Climate Change Projection Data by MOEJ (in cooperation with JMA)."
http://www.editoria.u-tokyo.ac.jp/projects/dias/

30----- Raw data are created in the format of Meteorological Research Institute, Japan Meteorological Agency, and utility of the general public is not assumed.

Summary

A detailed analysis of climate projections based on climate change models with a high spatial resolution with a view to improving climate projection information for climate change impact assessments in our country was conducted.

We hope the results of the climate projections will be used for establishing the "Adaptation Plan," which is currently under consideration, and practical operation of the Plan, and lead to the further promotion of climate change adaptation measures in our country.

We also hope readers of this publication will come to have stronger interest in future climate change in Japan, and that the publication contributes to deepening the understanding and consciousness of readers of what it means to project future climate and what is needed for that purpose.

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Climate in Japan at the end of 21st Century

Climate change projections considering the uncertainties