Specifications of Climate Change Projection Calculations

Outline of climate models used in this climate projection

The projection calculations are carried out using the Global Climate Model (GCM)\(^{13}\) and the Regional Climate Model (RCM)\(^{14}\), both developed by Meteorological Research Institute of Japan Meteorological Agency.

The GCM takes input data such as concentrations of greenhouse gases (GHG), ozone, and aerosols, sea surface temperature, sea-ice concentration, and sea ice thickness. The model requires sea surface conditions (i.e. sea surface temperature and sea ice), which are obtained from observations (for the present climate) and Coupled Model Intercomparison Project Phase 5 (CMIP5) model outputs (for the future climate).

To drive RCM with a higher resolution in a smaller region near Japan, we need GHG concentration and climatic conditions at regional boundaries as input data. The climatic boundary conditions are extracted from the results of calculations on the entire globe based on the GCM.

The present and future climates are reproduced and projected, respectively, with a spatial interval of approximately 60 km (i.e. resolution of the GCM) for the entire globe and with an interval of 20 km (i.e. resolution of the RCM) for Japan and its vicinity.

<table>
<thead>
<tr>
<th>Major specifications of climate-change projection models</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model name</strong></td>
</tr>
<tr>
<td>Spatial resolution</td>
</tr>
<tr>
<td>Area subject to calculation</td>
</tr>
<tr>
<td>Number of grids</td>
</tr>
<tr>
<td>Cumulus convection scheme</td>
</tr>
<tr>
<td>Main input conditions</td>
</tr>
</tbody>
</table>

(for information about abbreviations for sea surface temperature and cumulus convection scheme, see p.20 and 21)

---

\(^{13}\) For details, refer to Mizuta et al.(2012) andEndo et al.(2012).

\(^{14}\) For details, refer to Sasaki et al.(2011) and Sasaki et al.(2012).
Projection calculations with multiple case-settings

Case-settings for projection scenarios

We carried out calculations for 21 cases, which consist of three cases for the present climate and 18 cases for the future climate. The case-settings are shown below.

Case-settings of projection scenarios

<table>
<thead>
<tr>
<th>No.</th>
<th>Case name</th>
<th>Period</th>
<th>Emission scenario</th>
<th>Sea surface temperature</th>
<th>Cumulus convection scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HPA_m02</td>
<td>(Present experiment)</td>
<td>Observed value</td>
<td>Observed value</td>
<td>YS</td>
</tr>
<tr>
<td>2</td>
<td>HPA_kf_m02</td>
<td>Sept., 1984 - Aug., 2004</td>
<td></td>
<td></td>
<td>KF</td>
</tr>
<tr>
<td>3</td>
<td>HPA_as_m02</td>
<td></td>
<td></td>
<td></td>
<td>AS</td>
</tr>
<tr>
<td>4</td>
<td>HFA_rcp85_c1</td>
<td>RCP8.5</td>
<td>SST1</td>
<td></td>
<td>YS</td>
</tr>
<tr>
<td>5</td>
<td>HFA_kf_rcp85_c1</td>
<td></td>
<td>SST2</td>
<td></td>
<td>KF</td>
</tr>
<tr>
<td>6</td>
<td>HFA_as_rcp85_c1</td>
<td>(Future experiment)</td>
<td>SST3</td>
<td></td>
<td>AS</td>
</tr>
<tr>
<td>7</td>
<td>HFA_rcp85_c2</td>
<td>RCP6.0</td>
<td>SST1</td>
<td></td>
<td>YS</td>
</tr>
<tr>
<td>8</td>
<td>HFA_kf_rcp85_c2</td>
<td></td>
<td>SST2</td>
<td></td>
<td>KF</td>
</tr>
<tr>
<td>9</td>
<td>HFA_as_rcp85_c2</td>
<td></td>
<td>SST3</td>
<td></td>
<td>AS</td>
</tr>
<tr>
<td>10</td>
<td>HFA_rcp85_c3</td>
<td>RCP4.5</td>
<td>SST1</td>
<td></td>
<td>YS</td>
</tr>
<tr>
<td>11</td>
<td>HFA_kf_rcp85_c3</td>
<td></td>
<td>SST2</td>
<td></td>
<td>KF</td>
</tr>
<tr>
<td>12</td>
<td>HFA_as_rcp85_c3</td>
<td></td>
<td>SST3</td>
<td></td>
<td>AS</td>
</tr>
<tr>
<td>13</td>
<td>HFA_rcp60_c1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>HFA_rcp60_c2</td>
<td>RCP2.6</td>
<td>SST1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>HFA_rcp60_c3</td>
<td></td>
<td>SST2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>HFA_rcp45_c1</td>
<td></td>
<td>SST3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>HFA_rcp45_c2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>HFA_rcp45_c3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>HFA_rcp26_c1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>HFA_rcp26_c2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>HFA_rcp26_c3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(for information about abbreviations for sea surface temperature and cumulus convection scheme, see p.20 and 21)

15—— In the actual calculations, we carried out preparatory calculations (spin-up calculations) preceding the above periods to reduce the influences of initial conditions. The periods of spin-up calculations are approximately one year for the GCM and approximately 40 days for the RCM. The reason for setting the starting month at September is to reduce the influences of initial snow accumulation.
To quantify uncertainties in global warming projections, we conducted ensemble experiments\(^{16}\), in which calculations are performed a number of times for the same target period based on different conditions.

We used observed values of sea surface temperature (SST), sea-ice concentration, and sea-ice thickness for the experiments on the present climate. With respect to the experiments on the future climate, we used estimated values\(^{17}\), which were obtained by combining climate values and interannual variations. The climate values were created by adding future changes of model outputs to observed values used in the present climate experiments. The interannual variations were based on observed values.

---

### Emissions Scenarios

The future climate depends on GHG emissions scenarios. To take into account uncertainties among different emissions scenarios, we set input conditions such as future changes in sea surface temperature and GHG concentration levels, from the CMIP5 Model experiments based on the following four scenarios used in the Working Group I contribution to the IPCC Fifth Assessment Report (AR5) (IPCC, 2013). (For details of RCP scenarios, see p.23)

- RCP8.5 (high-level reference scenario)
- RCP6.0 (high-level stabilization scenario)
- RCP4.5 (intermediate-level stabilization scenario)
- RCP2.6 (low-level stabilization scenario)

Although AR5 presents the results of multiple model calculations based on RCP scenarios, this projection assumes average-level temperature increases among the AR5 calculation results, and carries out calculations for multiple cases based on average-level temperature increases. Therefore, it should be noted that the projection results in this publication do not reflect the entire uncertainty range of temperature increases of each RCP scenario. For example, the results reflect only part of the uncertainty range of the entire RCP2.6 scenario presented in AR5 when in this publication it is stated that the RCP2.6 scenario is equivalent to a specific temperature increase (see p.4).

---

### Future sea surface temperature change patterns

In climate change projections, sea surface temperature is a very important condition. The sea surface temperature condition is so important that the tendency of atmospheric temperature near the land surface, in particular, can be roughly determined by the condition.

Changes in the distribution of sea surface temperature also influence the climate in East Asia to a large extent through changes in the distribution of precipitation in tropical and monsoon regions. To take into consideration some of the uncertainties associated with the projections by evaluating influences due to differences in the distribution of sea surface temperatures, we analyzed a number

---

\(^{16}\)----- In climate change studies, calculations to reproduce the present climate and project the future climate are called "experiments." Hereinafter, we refer to climate projection calculations as experiments when it is preferable in order to be academically precise.

\(^{17}\)----- The methodology to construct ensemble experiments is based on the outcome of "Program for Risk Information on Climate Change: Theme C: Development of basic technology for risk information on climate change," conducted under the auspices of the Ministry of Education, Culture, Sports, Science and Technology.
of Atmosphere-Ocean General Circulation Models presented by CMIP5, and categorized the model sea 
surface temperatures obtained into three patterns (SST1, SST2, and SST3). Due to normalization in this 
categorization process, the global average of sea surface temperature changes is almost the same for 
all three patterns. It should be noted here that uncertainties in sea surface temperature changes are not 
reproduced in these projection calculations. In SST2, greater warming is found in the central and eastern tropical Pacific than the other patterns. 
SST2 reflects the average characteristics to a larger degree than the other patterns. In contrast, SST1 
shows less warming in the eastern tropical Pacific, which is the opposite to the characteristic of SST2. 
In addition, warming in the Southern Hemisphere is greater in SST1, to the extent that warming in the 
midlatitudes (−40°) is about the same between both hemispheres. SST3 has greater warming in the 
western North Pacific. Warming is greater than the other patterns also around the northern Indian 
Ocean and the North Atlantic. In contrast, warming in the Southern Hemisphere is smallest, so the 
interhemispheric contrast is large.

![Three sea surface temperature change patterns (unit: K)](image)
SST1: to the left; SST2: middle; SST3: to the right

**Cumulus convection parameterization**

For climate change projections covering Japan and its vicinity, it is considered to be especially 
important to assess uncertainties associated with projections of precipitation. To express uncertainties, 
calculations are performed using three types of cumulus convection parameterization (i.e. Yoshimura 
(YS) scheme, Kain-Fritsch (KF) scheme, and Arakawa-Schubert (AS) scheme) in projection calculations 
based on the GCM.

In the case of the RCM, however, the same cumulus convection scheme (Kain-Fritsch (KF) scheme) is 
used for all experiments. KF is known to be a scheme that can accurately depict convective activities 
around Japan. Its reproducibility for various climatic phenomena around Japan has been examined.

**Cumulus convection parameterization**

Cumulus clouds (a type of cloud with a cotton-like form, which often appears on clear days) 
typically appear and grow in tropical regions, transport moisture in an upward vertical direction. The 
moisture then condenses. The condensed moisture falls as rain or is released as cloud water. As a 
result, cumulus clouds play an important role as heat sources in the atmosphere, and have large 
influences on atmospheric circulation.

Currently available climate models usually do not have a sufficient resolving capability to directly 
depict cumulus clouds, except in some cases where well-developed cumulus clouds are described 
by localized models. Therefore, a mechanism for numerical forecasting models to redistribute heat 
and moisture in the vertical direction is adopted. This mechanism is called “cumulus convection 
parameterization.”

Prediction (2012)”

---

18——The detailed procedure for the categorization of sea surface temperature is as follows: (1) for each of the CMIP5 models, the annual-mean 
SST change from the present-day (historical experiment) to the end of the 21st century (RCP8.5 experiment) is computed; (2) the computed 
mean SST change is normalized by the tropical (30°S–30°N) mean SST change; (3) the multi-model ensemble mean of the normalized 
change is subtracted from that for each model experiment; (4) then, the inter-model pattern correlation over the tropics (30°S–30°N) 
is computed; and (5) distances are defined with the correlation and the cluster analysis is performed using these distances. For details, 
refer to Naito et al. (2014).

19——Refer to Yoshimura et al. (2014), Kain and Fritsch (1993), and Randall and Pan (1993) for YS, KF, and AS, respectively.
Cumulus congestus cloud: Cumulonimbus. It often exists when the atmosphere is unstable, and takes time for cumulus to become cumulonimbus. The height above the bottom of the cloud reaches several thousand meters or sometimes reaches 10,000 meters.

Towering cumulus: Cumulus climbs toward the sky by the upward current when the atmosphere is unstable. It often starts raining when the towering cumulus comes out.
Future scenarios for projection (RCP scenarios)

RCP scenarios are a set of selected scenarios of stabilization levels of greenhouse gas (GHG) concentrations in the future, as well as representative pathways to get to those levels, on the basis of implementation of political GHG mitigation (reduction) measures. Intergovernmental Panel on Climate Change (IPCC) started conducting climatic projections and impact assessments based on the above scenarios in the Fifth Assessment Report (AR5). Based on these scenarios, it has become possible to develop and examine multiple target-driven socioeconomic scenarios unlike projections based on the preceding SRES scenarios.

The numerical values following the term RCP indicate approximate total radiative forcing (RF) in the year 2100 against that in the year 1750 (unit: W/m²) for each scenario. This means that the larger the value is, the stronger the radiative force is in the year 2100 (scenarios with higher GHG emissions levels).


According to AR5, relationships among the four RCP scenarios and the magnitudes of global average temperature increases during the period 2081-2100 (compared to values for the period 1986-2005) are shown below. It can be said that as the values become smaller, the global-warming mitigation measures taken in the scenario become stricter.

Taking less strict mitigation measures

- RCP8.5: 3.7°C (2.6 to 4.8°C)
- RCP6.0: 2.2°C (1.4 to 3.1°C)
- RCP4.5: 1.8°C (1.1 to 2.6°C)
- RCP2.6: 1.0°C (0.3 to 1.7°C)

Taking stricter mitigation measures


---

20—— SRES scenarios: Set of scenarios used for “IPCC’s Fourth Assessment Report,” in which a variety of social, economic, and technological changes are first assumed, then a set of scenarios is developed based on estimated future GHG emissions corresponding to assumed levels of changes.

21—— Radiative forcing is a measure of the influence that a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism. Positive forcing tends to warm the surface, while negative forcing tends to cool it.