Synthesis Report on
Observations, Projections, and Impact Assessments of Climate Change

Climate Change and Its Impacts in Japan

October 2009

Ministry of Education, Culture, Sports, Science and Technology (MEXT)

Japan Meteorological Agency (JMA)

Ministry of the Environment (MOE)

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1. Introduction

The United Nations Framework Convention on Climate Change (UNFCCC), adopted in 1992, set out its ultimate objective as the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." It state that "such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner." To achieve this ultimate objective, various efforts to reduce greenhouse gas (GHG) emissions are ongoing, based on the Kyoto Protocol which was adopted in 1997 at the Third Conference of the Parties (COP3) of UNFCCC. International negotiations are also under way aiming at reaching an agreement at COP15 to be held in December 2009 on the framework beyond 2012 following the Kyoto Protocol's first commitment period (2008–2012).

In 2007, the Intergovernmental Panel on Climate Change (IPCC) published the fourth assessment report (AR4) as an exhaustive compilation of research results on climate change collected from around the world. It declared that "warming of the climate system is unequivocal." It also stated that "most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."

An overall picture of the climate change problem caused by anthropogenic GHGs can be summarized as shown in Figure 1. Carbon dioxide (CO_2), a major GHG, is generated when energy is produced by burning fossil fuels, and hence is deeply rooted in the socio-economic activities of humans. This GHG, not easily decomposed, remains in the atmosphere for a long time. If its emissions exceed sequestration by land ecosystems and oceans, the GHG concentration in the atmosphere will increase. Increases in GHG concentration lead to the warming of the Earth, triggering a range of phenomena including sea-level rise and exerting detrimental effects on ecosystems and human society. To cope with this climate change problem, it is necessary to implement both mitigation measures to control GHG emissions and adaptation measures to alleviate climate change impacts by modifying human, social, and economic systems, based on the adequate understanding of the climate system and the present state of climate change. In the long-term, it will be necessary to stabilize GHG concentrations at a level not imposing dangerous anthropogenic interference on the climate system as set out in the ultimate objective of the UNFCCC.

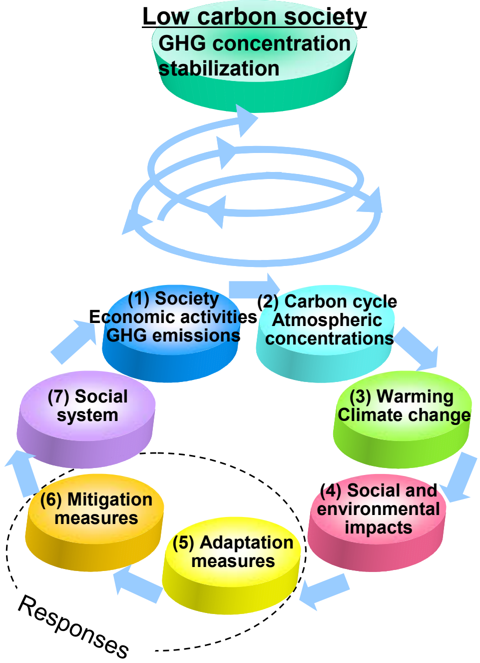

Fig. 1 Overall diagram illustrating the climate change problem

Source: Adapted from Hiramatsu et al., 2008

This report intends to present systematic information on the present state, future projection, and impacts of climate change in Japan mainly, as well as to provide the most updated scientific knowledge for use by national and local governments and the general public when deliberating on adaptation measures against climate change. To that end, this report primarily covers the changes in atmospheric GHG concentrations, the resulting climate change, and its impacts (mainly (2) through (4) and part of (5) in Fig. 1).

The structure of this report is as follows: Chapter 2 covers the mechanisms of climate change as basic knowledge for understanding the climate change problem and provides an answer to the question on what the causes of climate change are. Chapter 3 describes the present state (observation results) and future projections of climate change and address such questions as to whether global warming is really happening and how serious global warming will be in the future. Chapter 4 deals with the impacts of climate change on the environment and society and adaptation to those impacts. It also covers questions on what impacts and damage are likely to occur due to global warming and what adaptation measures are required. Chapter 5 provides an overview of the activities being taken for observations, projections, and impact assessments of climate change, and presents future perspectives.

To incorporate the latest research results as much as possible while ensuring scientific credibility, this report primarily relies on existing data and information including projections by climate models[1] that were presented in the IPCC AR4 major reports published by the national government itself and its committees and the results of government-supported comprehensive research projects. Explanations of terms useful for the understanding of this report and topics of public interest are provided in column sections.

In developing this report, the report structure and the contents were peer-reviewed by an Expert Committee (Chair: Shuzo Nishioka, Senior Visiting Researcher at NIES, the National Institute for Environmental Studies), which was specifically set up with experts in the fields of observations, projections, and impact assessments, in close cooperation with the JMA's Advisory Group of the Council for Climate Issues (Head: Hiroki Kondo, Principal Scientist, Global Warming Projection Research Project for IPCC AR5 at the JAMSTEC, Japan Agency for Marine-Earth Science and Technology).

2. Mechanisms of Climate Change and Contributions of Anthropogenic Factors — What are the Causes of Global Warming?

2.1 Factors affecting climate change

Climate change can be considered from two different aspects of the climate system: responses to external forcing and internal natural variability. The climate system is a system that forms and changes the climate through the dynamic interaction of the atmosphere, oceans, and land surface.

External forcing is a term denoting variability factors that have a diverse influence on the climate system and is comprised of external anthropogenic forcing and external natural forcing. Figure 2.1.1 gives an outline of radiative forcing, a typical external forcing related to energy. Typical external anthropogenic forcing includes the emissions of human-caused GHGs, aerosols[2], and other causative substances into the atmosphere. Land use changes, such as the conversion of forests into agricultural land and urbanization, are also included in the anthropogenic forcing. On the other hand, external natural forcing includes solar viability and volcanic eruptions. Volcanic eruptions exert a cooling effect on the Earth by causing aerosols turned from volcanic

[1] Physical equation-based models used for simulating climatic conditions in the past, present, and future with a supercomputer. See Columns 5 and 7.

[2] Fine solid or liquid particles suspended in the atmosphere. See Column 2.

gases, to block solar radiation. Climate change is triggered when the climate system begins to respond to these external forcings.

On the other hand, the internal natural variability of the climate system means variability induced not by external forcing but by the natural laws associated with the atmosphere, oceans, and land or their mutual interaction. Typical examples are the El Niño and La Niña phenomena which cause fluctuations of sea surface temperatures in the tropical Pacific on interannual time scales, but many other distinctive natural variabilities are also intertwined.

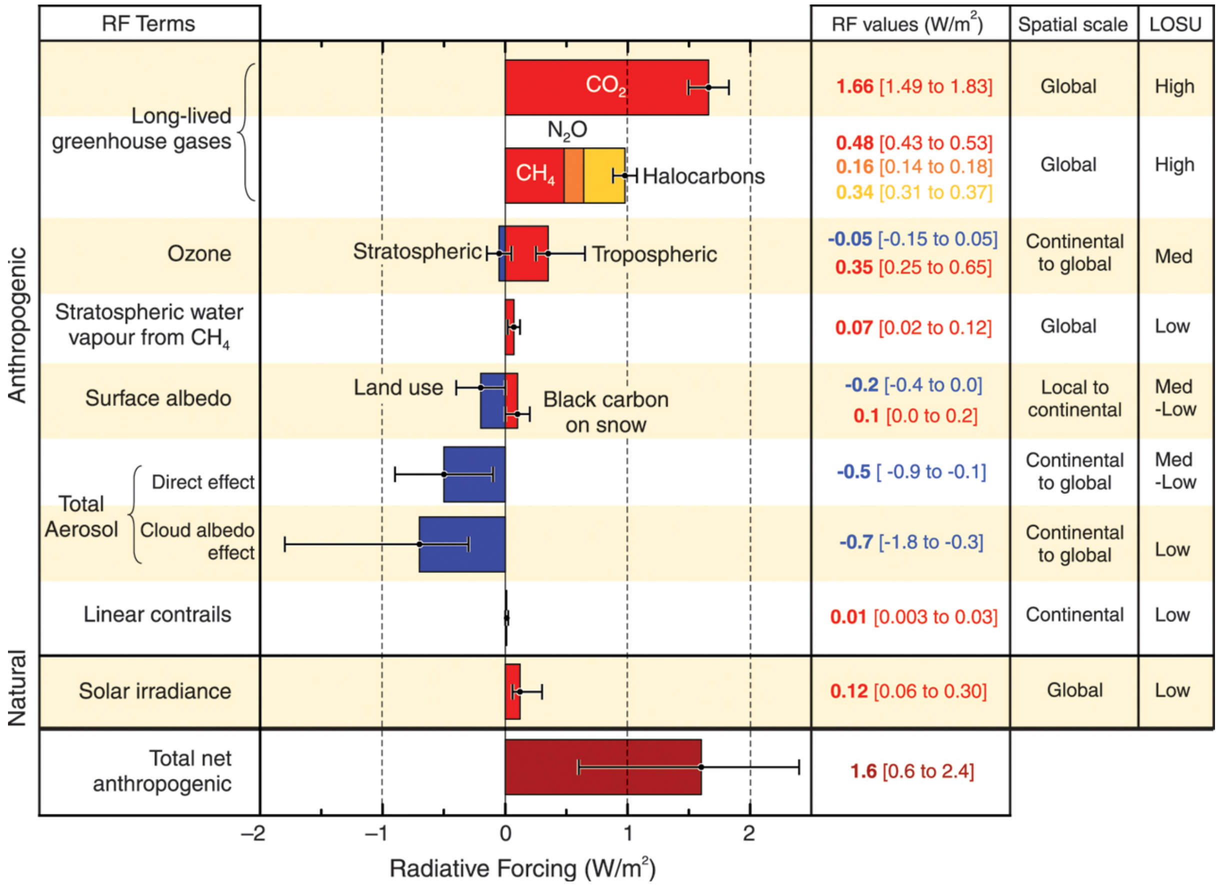

Fig. 2.1.1 Global average radiative forcing (RF) in 2005 (best estimates and 5 to 95% uncertainty ranges) with respect to 1750 for CO_2, CH_4, N_2O and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). Aerosols from explosive volcanic eruptions contribute an additional episodic cooling term for a few years following an eruption. The range for linear contrails does not include other possible effects of aviation on cloudiness.
Source: IPCC, 2007

2.2 The main cause of global warming since the mid-20th century is anthropogenic forcing

Actual climate change is caused by a combination of responses to various external forcings and natural variabilities. Therefore, to understand the climate change that occurred in the past, it is necessary to separate variabilities into those two types and examine them individually. Based on this approach, variations of global average temperatures in the 20th century were analyzed using climate models, the results of which are shown in Fig. 2.2.1.

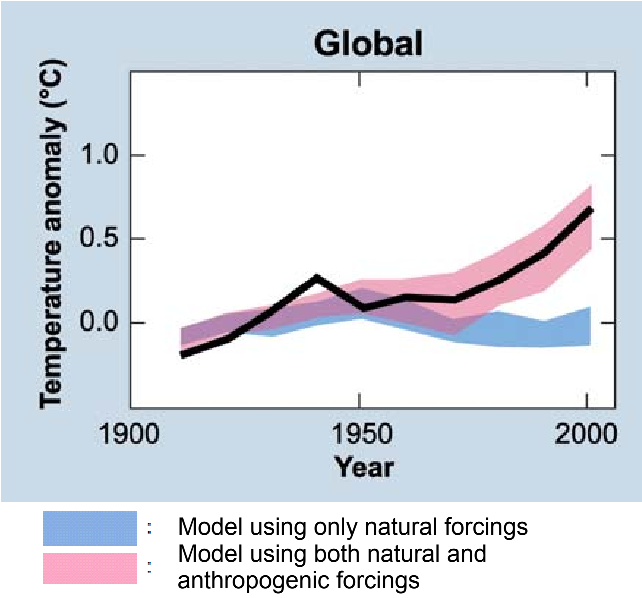

Fig. 2.2.1 Comparison of observed and global-scale changes in surface temperature with results simulated by climate models using only natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the 1901-1950. Blue shaded bands show the 5 to 95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5 to 95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings.

Source: IPCC, 2007

In this figure, the red shading is in good agreement with the black line with regards to the latter half of the 20th century[3]. This means that the global temperature rise in the latter half of the 20th century is readily explainable in terms of the responses to natural and anthropogenic external forcings known today. In contrast, the blue shading shows a slight decline of global temperatures in the latter half of the 20th century, a significant difference from the observed temperature rise shown by the black line. This indicates that the global temperature rise in the latter half of the 20th century is not accountable in terms of the responses to natural external forcing only.

Based on these research results, IPCC AR4 concluded that "Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."[4].

The effects of anthropogenic forcings are observed not only in the rise of global average temperatures but also in other trends, including variations in continental-scale average temperatures, increases in extreme high temperatures, decreases in extremely low temperatures, and other changes such as warming of oceans, wind variations like intensified westerly winds, and decreases in snow cover.

Concerning these results, care must be taken because some other external forcings not yet found by the present scientific knowledge may exist. For example, the possibility has been pointed out that, if the solar magnetic field decreased due to reduced solar activities, the cosmic radiation falling on the Earth would increase and then the Earth would be cooled due to increased clouds. However, there is increasing evidence indicating that the effect of solar activities is actually small. For example, even though solar activities weakened and the influx of cosmic radiation[5] increased from around 1985 to recent years, global temperatures rose during that period.

In the meantime, water vapor in the troposphere[6] which has a larger greenhouse effect than CO_2 is not treated as an external forcing in Fig. 2.1.1. This is because variations in the amount of water vapor,

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[3] Regarding the peak of the black line in the 1940s, it has been pointed out that there was a problem with the calibration method used for obtaining sea surface temperature data around World War II.

[4] "Very likely" means that the likelihood of occurrence is more than 90% probability. (This means that it is statistically significant with 10% risk based on the significance test by taking natural variabilities and the uncertainties of climate models into account.)

[5] Nuclei and elementary particles constantly falling onto the Earth from space at high speed. After reaching the Earth, cosmic radiation charges into the atmosphere and causes a nuclear reaction with the nuclei of oxygen and nitrogen in air.

[6] An atmospheric layer of the Earth existing in the range between the ground and an altitude of about 10 km. In the troposphere, air is stirred up by convection activities and the temperature is usually higher in the lower part of the layer.

radiation effects, and phase changes between cloud and rain are determined by factors within the climate system. These effects of water vapor are taken into account in all climate models.

2.3 Confidence in observation data and simulation results by models

Climate change is discussed based on the observation data of temperatures and observation data of each factor of external forcings, but caution is necessary because they contain uncertainties. Uncertainties are particularly significant with regard to the cooling effect of anthropogenic aerosols. Also, some raise a question that temperature observation stations are overly concentrated in city areas. However, many observation stations also exist in areas other than cities, including over the oceans, and observation data covering nearly the entire Earth, excluding the Arctic and Antarctic regions, have become available, particularly after the mid-20th century. Therefore, as far as global average temperatures are concerned, the effect of urbanization is very small.

The results of simulation by climate models also contain uncertainties. Climate models are basically based on physical laws, but it is impossible to express all of the complicated climate system using only physical laws, and hence semi-empirical assumptions are incorporated partly. If those assumptions differ, the results also differ. As a result, uncertainties are involved in the simulations of past climates and projections of future climates. In particular, changes in clouds associated with warming vary by model, causing an influence on the simulations of temperature rises and other factors. But climate models adopted in IPCC AR4 can largely reproduce spatial distribution and time variability characteristics, such as atmospheric winds, atmospheric temperatures, atmospheric pressures, water vapor, oceans currents, seawater temperatures, salinity, sea ice, surface air temperatures, and snow cover. It can also reproduce many typical natural variations observed in the actual climate system. From this, it can be said that climate models have a certain level of confidence. Hence, we have used the results of those models for assessment after checking the range of uncertainties using multiple models.

2.4 Changes on longer time scales and particularity of recent change

According to the temperature data of the last 1,000 years or so (Fig. 2.4.1) which was indirectly estimated from alternative data such as tree rings, there is the possibility that average temperatures in the northern hemisphere declined by up to 1°C around the 17th century and this is called the little ice age[7]. Today, it is known that this type of past temperature variation is broadly explainable from variations in solar activities and volcanic eruptions. However, as known from the fact that the temperature rise continued from around 1985 to recent years even though solar activities were weak during that period, temperature variations in the latter half of the 20th century are not explainable from solar activities and volcanic eruptions. It is therefore impossible to consider that recent warming is a natural recovery from the little ice age.

During the past several hundreds of thousand years, a cycle of a glacial period (lasting about 100,000 years) followed by an interglacial period (lasting from 10,000 to 30,000 years) has been repeated (Fig. 2.5.2). This cycle of glacial-interglacial periods is considered to have been caused by periodic changes in the orbit and inclination of the rotational axis of the Earth. The present period is an interglacial period and the next glacial period will come in the future. The next glacial

[7] A cycle of cold-warm periods has been repeated over the past several hundreds of thousand years. Cold periods are called "glacial periods" and the warm period between two glacial periods is called an "interglacial period". The present period is an interglacial period. The period around the 17th century immediately before the beginning of the present-day global warming is called a little glacial period, because it was the coldest period in the present interglacial period.

period is projected to come more than 30,000 years later, according to rigorous astronomical calculations.

Atmospheric GHG concentrations in the past also varied greatly due to natural factors like the glacial-interglacial cycle. Figure 2.4.2 shows that the concentrations of GHGs, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), were high in the interglacial period, when temperatures were rather mild, compared with their concentrations in the cold glacial period. The difference in CO_2 concentration between the coldest period of the glacial period and the interglacial period was about 100 ppm.[8] This kind of variation is considered to be attributable to the climate change that occurred due to the alteration of GHGs concentration, such as CO_2, triggered by another climate change invoked by periodic changes in the orbit and inclination of the rotational axis of the Earth. As seen, the trigger is different from that of present-day climate change, which was preceded by the alteration of GHG concentrations.

Concerning the variations in GHG concentrations in the glacial and interglacial cycles, the present-day concentrations (concentrations in the year 2000 are shown with an asterisk in Fig. 2.4.2) are by far the highest compared with those of any other interglacial periods in the last 650,000 years, suggesting that increases in GHG concentrations in recent years are extremely unusual even in the long history of the Earth's atmosphere.

An increase of about 100 ppm in CO_2 concentration due to natural factors that occurred in the period from the last glacial period[9] to the Holocene[10] took about 7,000 to 8,000 years, but the increase of 100 ppm after the Industrial Revolution due to anthropogenic factors occurred within only 250 years.

According to IPCC AR4, ice sheet analysis reveals that the CO_2 concentration before the industrial revolution in the 18th century was about 280 ppm but continued to increase to reach 383 ppm in 2007. It was also found that CH_4 concentration more than doubled, from about 715 ppb[11] in the pre-industrial period to 1789 ppb in 2007. The N_2O concentration also increased to 321 ppb from about 270 ppb in the same period.

Looking at the period after the Industrial Revolution, the speed of increase in CO_2 concentration of about 100 ppm was not constant. To be specific, it took more than 200 years for the first 50 ppm increase, but the next 50 ppm increase occurred within only 30 years. Furthermore, the increase from 1997 to 2007 was 2.0 ppm per year, clearly indicating an acceleration in the speed.

In Japan, observations of CO_2 concentration are being conducted at observation stations in such areas as the Cape Ochi-ishi (Hokkaido), Ryori (Iwate), Minamitorishima (Tokyo), Yonagunijima (Okinawa), and Hateruma (Okinawa) (Fig. 2.4.3). Observations at these stations have captured the trend of secular concentration increase and larger seasonal variations as the latitude becomes higher (Fig. 2.4.4), a trend roughly in agreement with other observations in the world.

8 ppm: part per million ($1/10^6$) by volumetric ratio.

9 The most recent glacial period that started about 70,000 years ago and ended about 10,000 years ago. It is also called the Würm glacial period.

10 The period which started about 10,000 years ago when the last glacial period ended and continues up to the present day.

11 ppb: part per billion ($1/10^9$), by volumetric ratio.

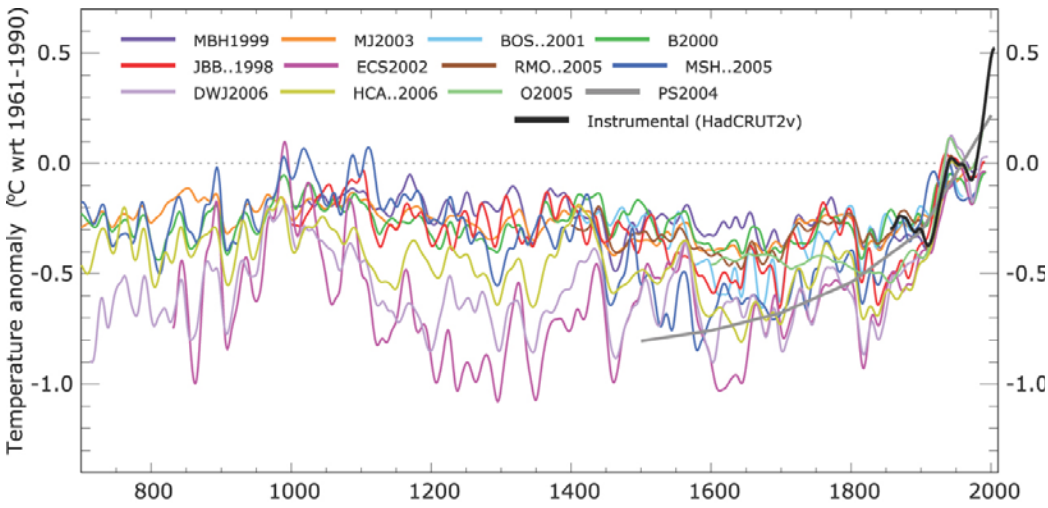


Fig. 2.4.1 Records of Northern Hemisphere temperature variation during the last 1300 years with 12 reconstructions using multiple climate proxy records shown in colour and instrumental records shown in black.
Source: IPCC, 2007

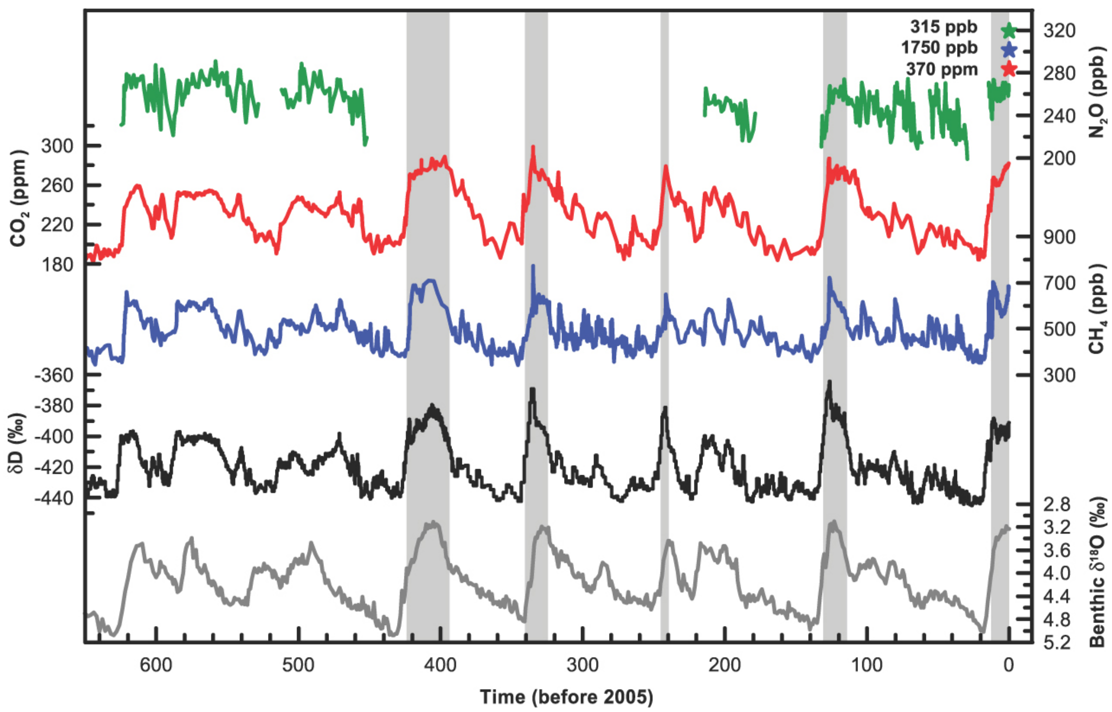


Fig. 2.4.2 Variations of deuterium (δD; black), a proxy for local temperature, and the atmospheric concentrations of the greenhouse gases CO_2 (red), CH_4 (blue), and nitrous oxide (N_2O; green) derived from air trapped within ice cores from Antarctica and from recent atmospheric measurements. The shading indicates the last interglacial warm periods. Interglacial periods also existed prior to 450 ka, but these were apparently colder than the typical interglacials of the latest Quaternary. The length of the current interglacial is not unusual in the context of the last 650 kyr. The stack of 57 globally distributed benthic $\delta^{18}O$ marine records (dark grey), a proxy for global ice volume fluctuations, is displayed for comparison with the ice core data. Downward trends in the benthic $\delta^{18}O$ curve reflect increasing ice volumes on land. Note that the shaded vertical bars are based on the ice core age model, and that the marine record is plotted on its original time scale based on tuning to the orbital parameters. The stars and labels indicate atmospheric concentrations at year 2000.
Source: IPCC, 2007

As seen above, GHG concentrations have been increasing very quickly in recent years. It can be said that forcings imposed on the climate system are increasing at an unprecedented speed.

Based on these facts, the discussions on the climate change in Japan presented in Chapter 3 or later will focus on the period from around 1900 to 2000 when anthropogenic forcings exerted a particularly significant effect.

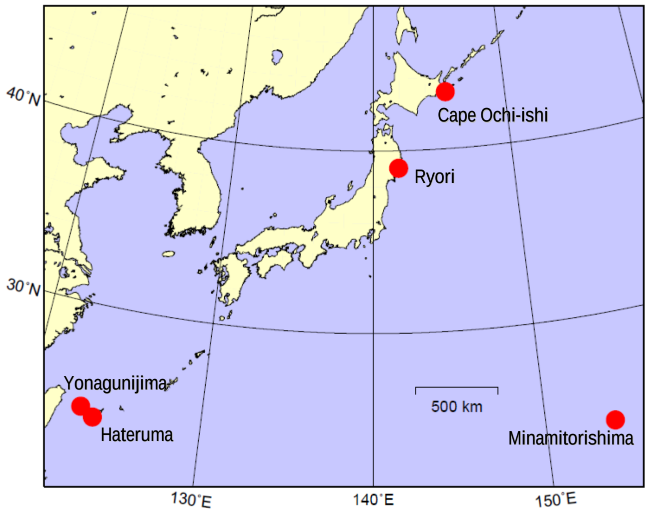


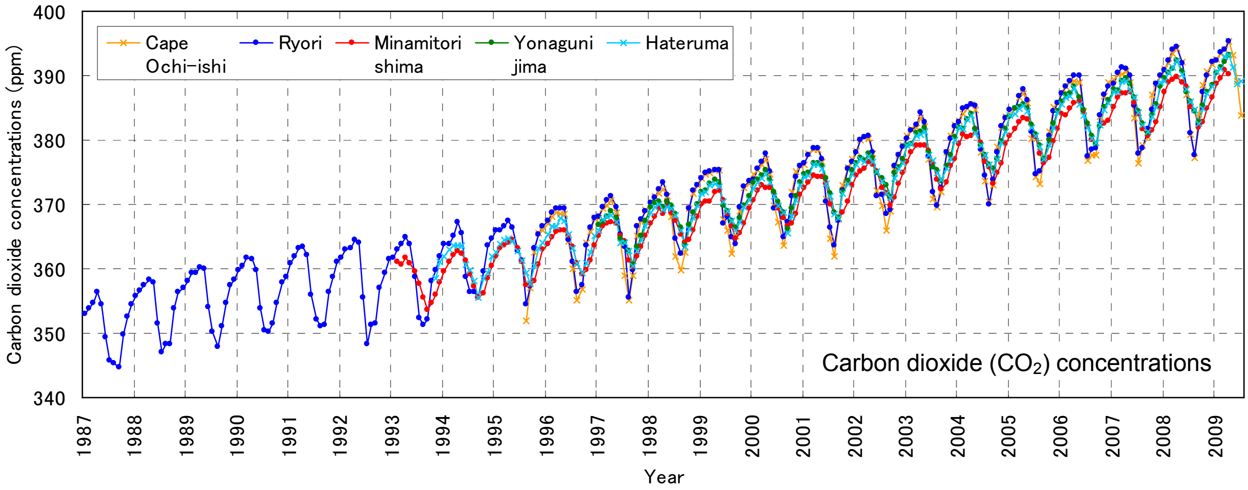
Fig. 2.4.3 Observation stations of GHG concentrations in Japan

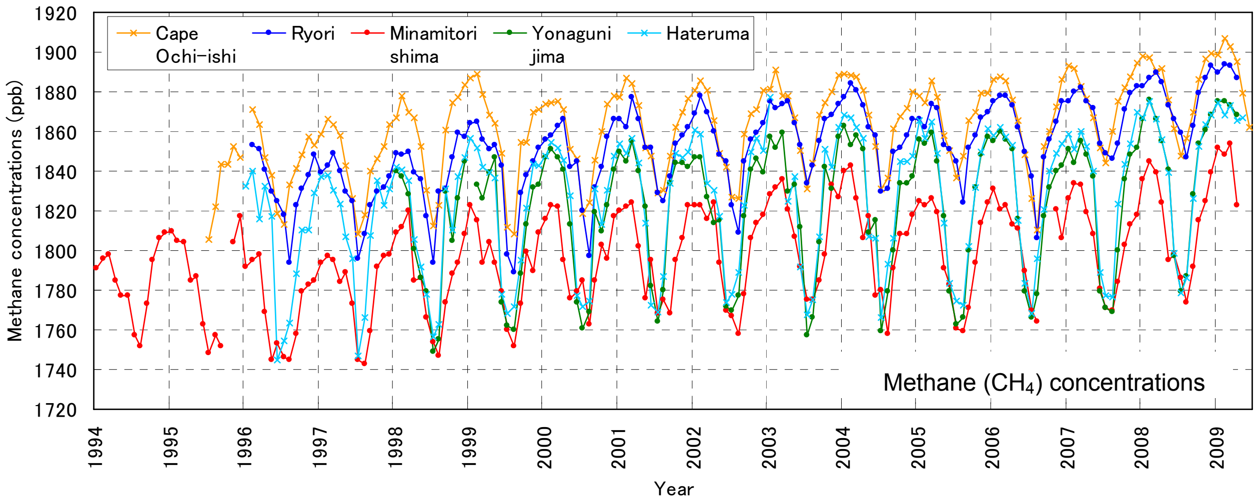
[Column 1] Definitions of Terms Related to Climate Change

"Climate" is a term denoting the state derived by averaging the state of the atmosphere, oceans, and others over a sufficiently long period of time. The average over a sufficiently long period of time usually means a 30-year average (the average from 1971 to 2000 at present) based on a statistical methodology adopted in the World Meteorological Organization (WMO).

"Climate variability" means variations from the average climate or other statistics (standard deviations, frequency of extreme values, etc.) on all temporal and spatial scales larger than individual weather events. It includes short-term variations on temporal scales of seasonal, interannual, and longer. Examples are variations of extreme events such as heat waves, droughts, heavy precipitation, tropical cyclones (typhoons, hurricanes), as well as El Niño and La Niña phenomena.

On the other hand, "climate change" refers to a long-term changing trend of climate. It means clearly noticeable changes in the average state of climate over a period of at least several decades, captured by such recognition of weather as warmer as or drier than before, or of duration of sunshine as longer or shorter than before. Note that this term is usually used for all the observed changes as appears in the IPCC documents regardless of their cause, be it natural or anthropogenic. But, in the UNFCCC documents, this term is used under definition only to mean climate change induced by anthropogenic causes.





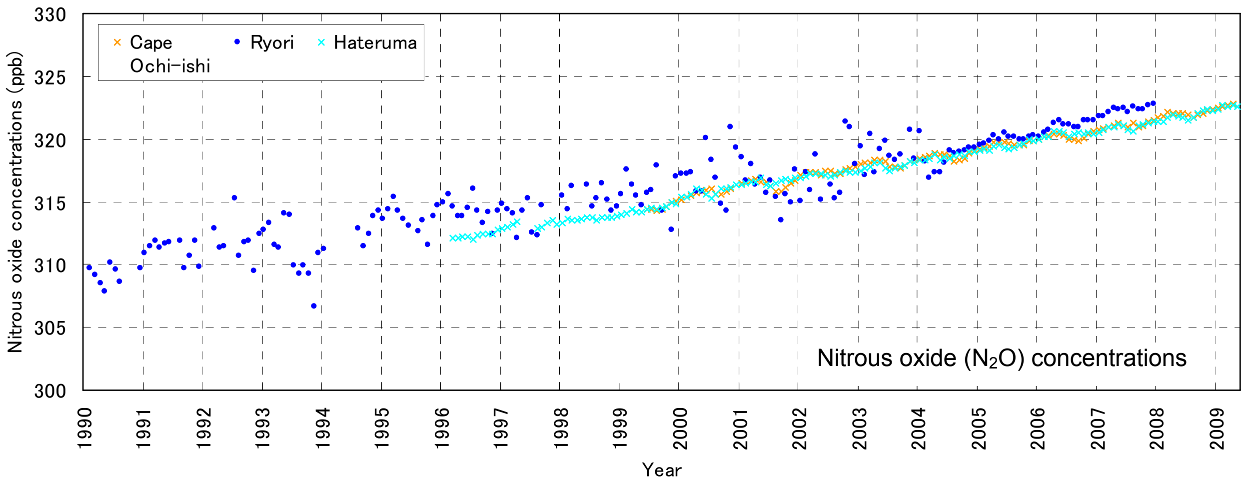


Fig. 2.4.4 Observed GHG concentrations in Japan

Adapted from observation data at JMA and the National Institute for Environmental Studies (NIES)

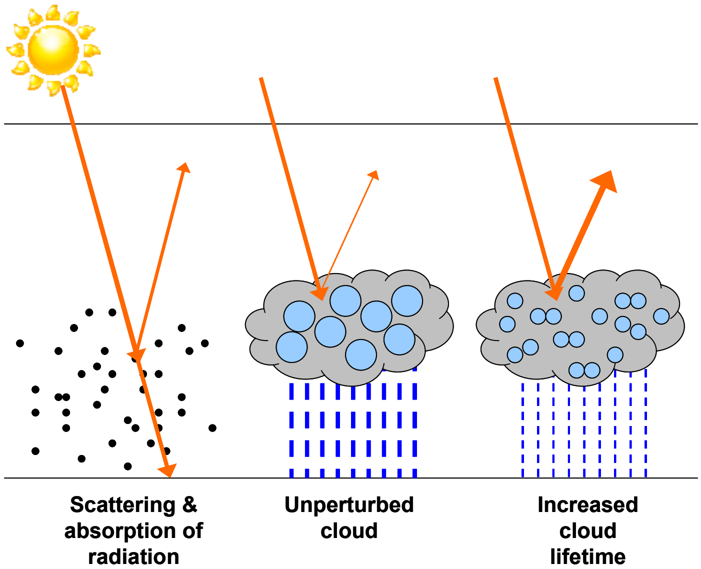
N_2O concentrations at Ryori before February 2004 show a large scatter because a different observation method from the current one was used at the time.

[Column 2] Aerosols and Climate Change

Aerosols are fine particles suspended in the atmosphere, with a radius of about 0.001 μm[12] to 10 μm. They include sulphate and nitrate generated from anthropogenic and natural gases; mineral dust (such as yellow sand) blown up by winds; sea salt produced from seawater; and black carbons and organics generated from the burning of fossil fuels and biomass. Aerosols scatter and absorb solar radiation and alter the properties and state of clouds by becoming nuclei of cloud drops. They are considered to have an effect on the climate through these processes.

Past IPCC reports provided a view that the temperature rise due to CO_2 and other GHGs simulated by climate models is greater than the observed temperature rise, and this is because anthropogenic sulphate and organic aerosols resulted from tropospheric air pollutions control such temperature rise (aerosols containing black carbon are said to have a greenhouse effect). But, compared with GHGs such as CO_2, tropospheric aerosols are short-lived in the atmosphere and highly variable in chemical compositions and concentrations. Therefore, their effects on climate change have not been well clarified yet, and IPCC AR4 mentioned that the level of scientific understanding (LOSU) on aerosols is still low (see Fig. 2.1.1 in this report).

Aerosols exert two types of effects to control temperature rise: the direct effect is to scatter and absorb solar radiation and the indirect effect is to alter the physical and optical properties of cloud drops by becoming condensation nuclei[13] in cloud generation (cloud albedo effect). This indirect effect is further classified into two types of effects that occur when cloud drops reduce their size as the number of condensation nuclei or their concentration increases: one is an increase in solar reflectance because the portion of white cloud increases due to the size reduction of the cloud drops; the other is long-retention of clouds because rainfall becomes less likely due to the size reduction of the cloud drops. In the northern hemisphere, mainly in Asia where human activities are growing, emissions of sulfur dioxide gas and volatile organics[14] are increasing and anthropogenic aerosols generated from them is also on the rise. According to analysis of satellite images, the size of cloud drops tends to be small in the northern hemisphere where the number of aerosols or their concentration is greater compared with the southern hemisphere. Currently, research is under way to minimize uncertainties associated with the estimation of radiative forcings by clarifying the relationship between aerosols and cloud generation.



Schematic diagram showing radiative mechanisms of clouds related to aerosols

Left: the small black dots represent aerosols which scatter and absorb radiation. Middle: a cloud containing large cloud drops which causes rainfall but has a small solar reflectance. Right: a long-lived cloud with a larger solar reflectance than a cloud containing large cloud drops.

Source : Adapted from IPCC, 2007.

12 1 μm (micrometer) : a length of 1/1,000 of 1 mm.

13 Substances that become nuclei of clouds (aerosols, etc.). If condensation nuclei are abundant in the atmosphere, atmospheric water vapor is likely to form a cloud (water drops, ice crystals) when it is cooled, and unlikely to form a cloud when it is not cooled.

14 Organic substances that transform from a liquid to a gas at normal temperature. Typical chemical substances include formaldehyde and toluene which are contained in housing construction materials, wallpaper, and furniture. It is also called Volatile Organic Compounds (VOC).

3. Past, Present, and Future of the Climate — What is the Current State and Future of Global Warming?

3.1 Observed climate change — Is global warming really happening?

In Japan, weather stations began to be set up in various parts of the country in the 1870s and meteorological observations using instruments were launched. By 1885, 30 weather stations had been established by the efforts of the Land Development Bureau of Hokkaido, the Geographical Survey Bureau of the Ministry of the Interior, each prefectural government, and local volunteer groups, but the observation and statistical methodologies they used varied. With the enactment of the Meteorological Observation Law in 1886, observation and statistical methodologies were standardized and such standardized methodologies have since been employed in Japan. At present, surface weather observations are being carried out at about 160 meteorological observatories and weather stations distributed across the country. In addition, automatic observations of temperature, precipitation, and other elements are being performed over the network called Automated Meteorological Data Acquisition System (AMeDAS) of about 1,300 observation stations, including meteorological observatories and weather stations.

Some of those observation stations have kept long-term records since the end of the 19th century, which provide valuable information for tracking climate change in Japan. It is important that the uniformity of observation data is maintained over a long period to enable an understanding of climate change. If some observation stations are transferred, they should be evaluated to see if their data is usable as continuous data. In dealing with global warming, care must be taken regarding area-specific anthropogenic impacts such as urbanization.

From these viewpoints, the following observation records are used in this report to understand climate change in Japan: in terms of precipitation, which is rarely influenced by urbanization, we use observation records obtained at 51 observation stations where the uniformity of observation data has been maintained; in terms of temperature, which is substantially influenced by urbanization, we use observation records obtained at 17 observation stations (Fig. 3.1.1) where urbanization is not very advanced besides the uniformity of records has been maintained. Those observation stations are not fully free from environmental impacts such as urbanization, but we believe that their observation records are appropriate for monitoring natural variability in the climate and temperature change caused by global warming, based on the comparison with the marine data, which bears no relation to urbanization (Column 3).

Regarding oceanographic and marine meteorological observations in the ocean, the observation, recording, and data collection using standardized methodologies began in the end of the 19th century. Marine observations have been carried out by research vessels and other ships in the world, including merchant vessels. In recent years, automatic observation devices such as drifting buoys[15] and Argo floats[16] have been deployed and they cover areas inside and outside the oceans routes, constituting observation network over the world oceans, accounting for 70% of the Earth's surface, in combination with the conventional observations. Sea surface temperature data, which is historically rich, is useful substitute for marine surface air temperature data and is utilized for obtaining global average temperatures. Sea level data providing sea surface variations is also important for detecting variations in the density of subsurface seawater.

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[15] Observation instruments those automatically measuring elements such as atmospheric pressure, water temperature, and wave height while drifting on the sea surface.

[16] Observation instrument that can measuring elements such as water temperature and salinity, while automatically moving up and down in a range between the sea surface and a depth of 2,000 m.

In this chapter, we will describe the actual situation of climate change in the world and Japan, which has been identified using these various data.

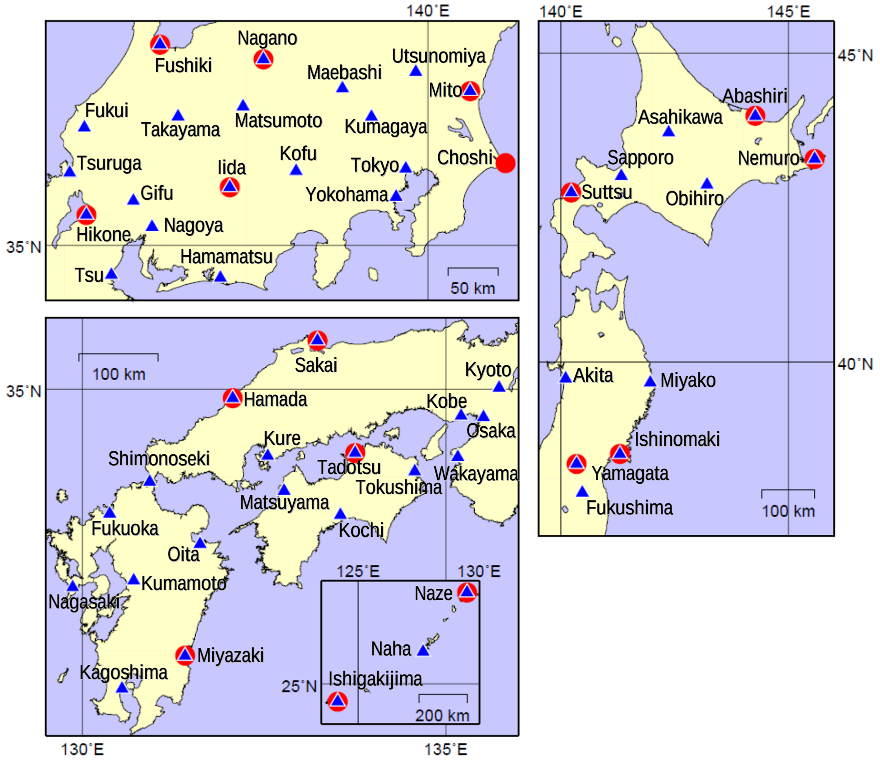


Fig. 3.1.1 Observation stations whose data are used to estimate the surface temperature and precipitation in Japan

The blue triangles represent the 51 observation stations for deriving precipitation ratios and the red circles are the 17 observation stations for deriving average temperature anomalies.

(1) Changes in temperature

The annual temperature in Japan has been rising at a rate of 1.1°C per century since 1898. High-temperature years have been particularly frequent after the 1990s. As temperatures rise, the numbers of days with minimum temperatures (T_{min}) of ≥ 25°C and days with maximum temperatures (T_{max}) of ≥ 35°C are increasing respectively, while that of days with T_{min} < 0°C is decreasing.

Global average temperatures [17] have been increasing at a rate of 0.7°C per century since the mid-19th century in the long-term while varying on a broad range of time scales (Fig. 3.1.2). Variations of global average temperatures obtained from the observed data are likely due to the combination of a long-term rising trend of temperatures and natural variations, such as high and low temperatures associated with the El Niño and La Niña phenomena, Pacific Decadal Oscillation (PDO), and episodic temperature declines due to volcanic eruptions.

The rising trend of global average temperatures since the mid-19th century is very sharp, unprecedented even in the temperature changes over the past 1,300 years (Fig. 2.5.1).

[17] To estimate global average temperature anomalies, observation data not only on land but also on oceans are used.
To eliminate region-to-region variations, we obtain average temperature deviation from normal (value of the base period) in each 5° latitudinal × 5° longitudinal grid both over land and oceans, and then average the values multiplied by the areal weight that varies by latitude, to derive the global average temperature anomalies (average deviation from normal).

In particular, most of temperature rises since the mid-20th century are very likely to be attributable to the increases in anthropogenic GHG concentrations.

Temperature rises are not uniform across the world, but vary by region. In Asia, temperature rises are particularly significant in mid- to high-latitude regions such as North Asia and Central Asia. In those regions, the rising trend is particularly noticeable in winter (December to February) and in spring (March to May) (Table 3.1.1).

The long-term trend of the annual temperature anomaly in Japan is about 1.1°C per century (statistical period: from 1898 to 2008) (Fig. 3.1.3).

The period of relatively low temperatures continued up to the 1940s, but temperatures began to rise abruptly in the latter half of the 1980s. The years that recorded significantly high temperatures are concentrated in the period after 1990. The cause behind the frequent appearance of high temperature in recent years is considered to be a combination of global warming due to increased emissions of GHGs and natural variations on the time scale of several years to several decades, similar to the cause behind the rise of global average temperatures.

Significant temperature rise is found in all seasons for the all four areas of Japan — Northern, Eastern, Western Japan, and Okinawa-Amami — (Table 3.1.2).

Such warming trend is also seen in the numbers of days with maximum temperatures (T_{max}) of ≥30°C, days with T_{max} of ≥35°C, days with minimum temperatures (T_{min}) of ≥ 25°C, and days with T_{min} of < 0°C respectively. The numbers of days with T_{max} of ≥35°C and days with T_{min} of ≥ 25°C significantly increased over the past 78 years between 1931 and 2008. Also, the number of days with T_{min} < 0°C significantly decreased at a rate of 2.3 days per decade. The number of days with T_{min} < 0°C decreased by about 10 days in the last three decades compared with the first three decades from 1931 (Fig. 3.1.4, Table 3.1.3).

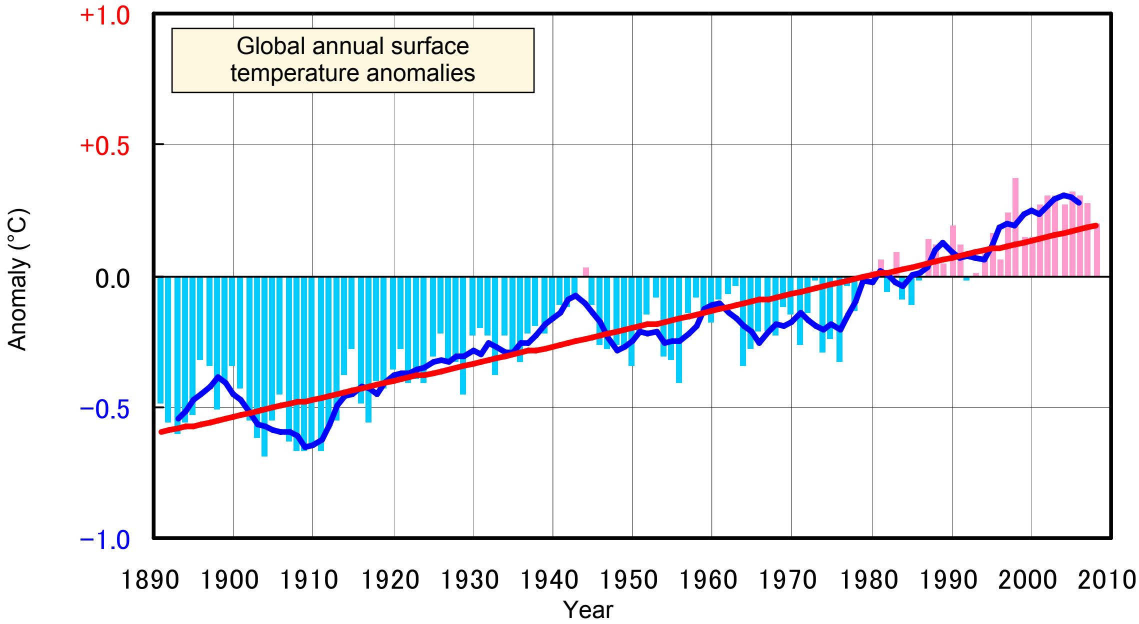


Fig. 3.1.2 Global annual surface temperature anomalies from 1891 to 2008

The bar represents anomalies in surface temperature from the normal (i.e. the 1971 – 2000 average). The heavy line (blue) shows the five-year running mean. The straight line (red) is the long-term linear trend.

Source: JMA, 2009

Table 3.1.1 Long-term trend in annual and seasonal average surface temperatures anomalies on land in the world and in each region (°C / century)

	Annual	Spring (Mar. to May)	Summer (Jun. to Aug.)	Autumn (Sep. to Nov.)	Winter (Dec. to Feb.)
Global	+0.74	+0.85	+0.51	+0.56	+1.06
N. Hemisphere	+0.77	+0.89	+0.50	+0.57	+1.13
S. Hemisphere	+0.71	+0.77	+0.69	+0.63	+0.76
North Asia	+0.99	+1.75	+0.52	+0.34*	+1.36
Central Asia	+1.50	+1.63	+0.83	+1.16	+2.33
East Asia	+0.52	+0.83	-0.02*	+0.15*	+1.10
South Asia	+0.56	+0.35	+0.40	+0.73	+0.78
Europe	+0.79	+0.92	+0.78	+0.60	+0.85
North America	+0.80	+0.86	+0.51	+0.60	+1.31
Central America	+0.08*	+0.04*	+0.30	+0.18*	-0.21*
South America	+1.10	+1.01	+1.09	+1.19	+1.15
North Africa	-0.10*	-0.07*	-0.26*	+0.08*	-0.15*
South Africa	+0.29	+0.41	+0.16*	+0.17*	+0.38
Oceania	+0.46	+0.50	+0.46	+0.37	+0.55

Long-term trends obtained by linear regression analysis. Statistical period: Southern Hemisphere 1887 to 2004, North Asia 1883 to 2004, North Africa 1904 to 2004, South Africa 1897 to 2004, South America 1892 to 2004, All other regions 1880 to 2004. Values marked with an asterisk indicate that those increasing or decreasing trends are not significant with a 95% confidence level.

Source: Adapted from JMA, 2005a.

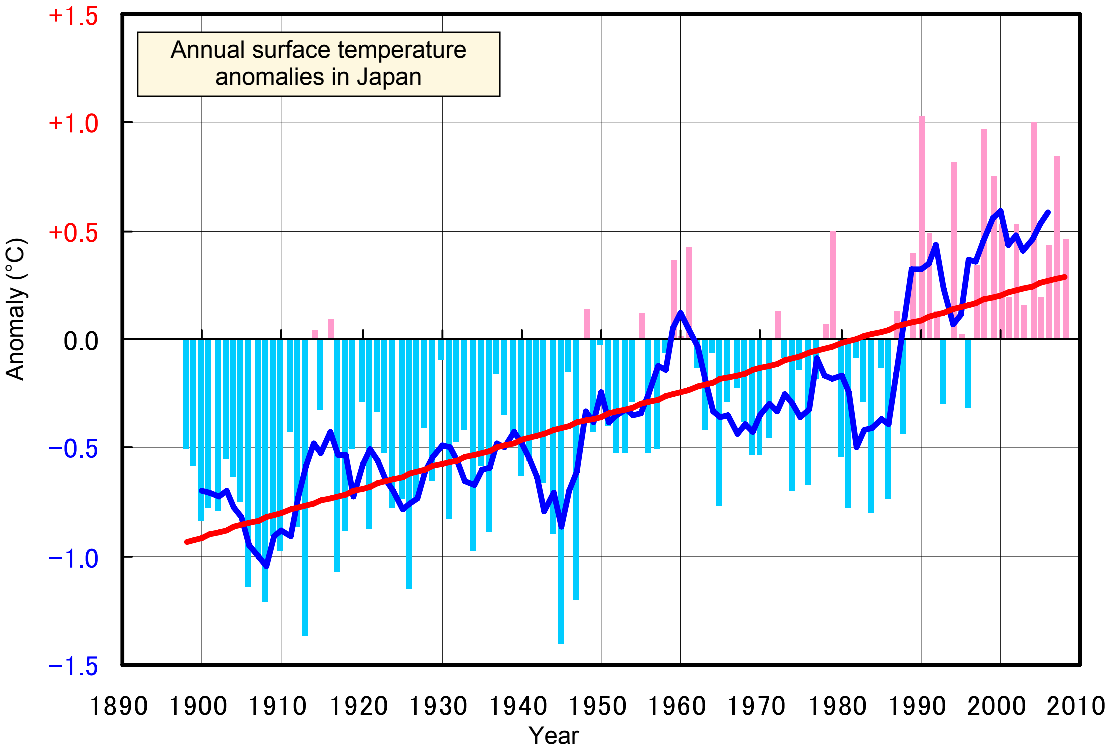


Fig. 3.1.3 Annual surface temperature anomalies from 1898 to 2008 in Japan

Annual surface temperature anomalies obtained at 17 observation stations (Fig. 3.1.1) are shown. The bar graph represents anomalies from normal (i.e. the 1971 – 2000 average). The heavy line (blue) shows the five-year running mean. The straight line (red) is the long-term trend. Source: JMA, 2009

Table 3.1.2 Long-term trend in annual and seasonal average surface temperatures in Japan

(°C /century)

	Year	Spring (Mar. to May)	Summer (Jun. to Aug.)	Autumn (Sep. to Nov.)	Winter (Dec. to Feb.)
Entire Japan	+1.11	+1.35	+0.92	+1.07	+1.13
Northern Japan	+1.01	+1.30	+0.59	+0.80	+1.34
Eastern Japan	+1.13	+1.41	+0.88	+1.06	+1.19
Western Japan	+1.22	+1.46	+1.20	+1.29	+0.96
Okinawa/Amami	+1.06	+1.04	+1.18	+1.21	+0.82

Long-term trends obtained by linear regression analysis. Statistical period: 1898 to 2008. Regardless of the area and season, all increasing trends are significant with a 95% confidence level. Observation stations used for this estimation: Northern Japan (Abashiri, Nemuro, Suttsu, Yamagata, Ishinomaki); Eastern Japan (Fushiki, Nagano, Mito, Iida, Choshi); Western Japan (Sakai, Hamada, Hikone, Miyazaki, Tadotsu); Okinawa/Amami (Naze, Ishigakijima)

Source: Adapted from JMA, 2005a.

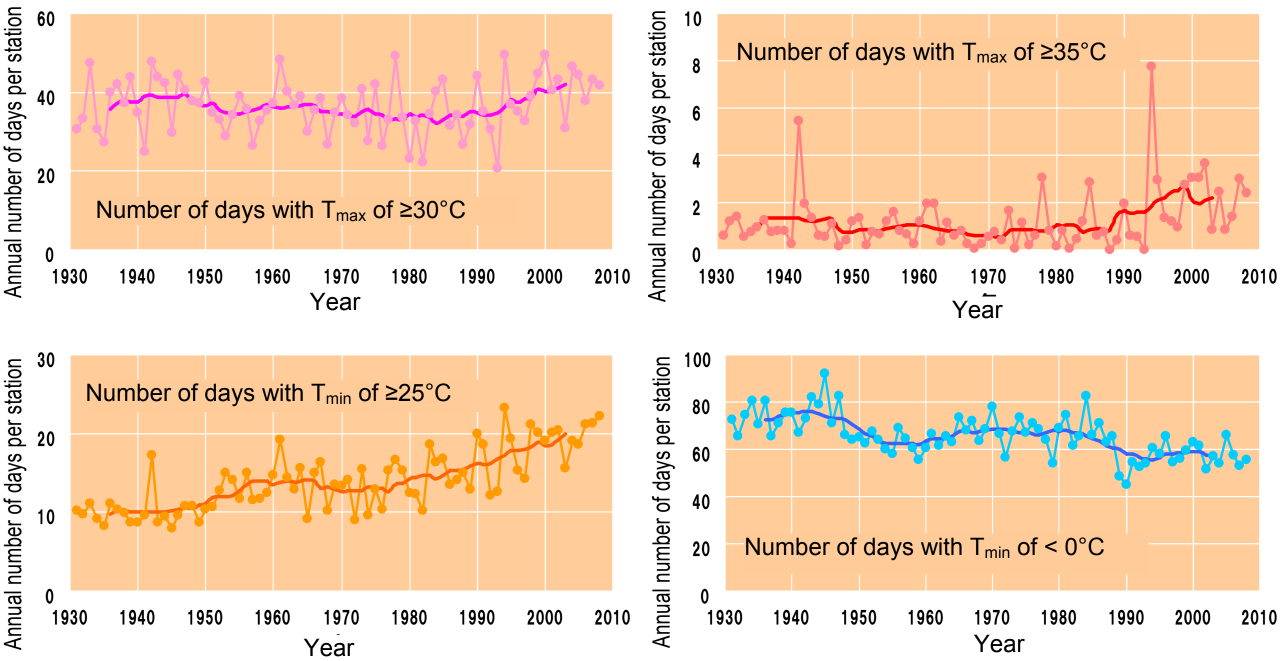


Fig. 3.1.4 Changes in the annual number of days with T_{max} of ≥30°C (upper left), days with T_{max} of ≥35°C (upper right), days with T_{min} of ≥25°C (lower left), and days with T_{min} of < 0°C (lower right) in Japan

Annual number of occurrence days per station calculated from data taken at 15 observation stations (Abashiri, Nemuro, Suttsu, Yamagata, Ishinomaki, Fushiki, Nagano, Mito, Choshi, Sakai, Hamada, Hikone, Tadotsu, Naze, Ishigakijima). The thin line shows the annual number of days. The heavy line shows the 11-year running mean.

Source: JMA, 2009

Table 3.1.3 Long-term trend of the annual number of days with T_{max} of ≥30°C, days with T_{max} of ≥35°C, days with T_{min} of ≥25°C, and days with T_{min} of < 0°C in Japan

Number of days with T_{max} of ≥30°C		
Trend +0.21 day/10 years	Average number of days from 1931 to 1960	36.5 days
	Average number of days from 1979 to 2008	36.6 days
Number of days with T_{max} of ≥35°C		
Trend +0.15 day/10 years (significant)	Average number of days from 1931 to 1960	1.0 day
	Average number of days from1979 to 2008	1.6 days
Number of days with T_{min} of ≥25°C		
Trend +1.31 days/10 years (significant)	Average number of days from 1931 to 1960	11.0 days
	Average number of days from 1979 to 2008	17.1 days
Number of days with T_{min} of < 0°C		
Trend -2.29 days/10 years (significant)	Average number of days from 1931 to 1960	69.8 days
	Average number of days from 1979 to 2008	60.0 days

Based on the annual number of occurrence days per station calculated from data taken at 15 stations (Fig. 3.1.4). Statistical period: 78 years from 1931 to 2008. The trend is represented by the trend in the number of days (inclination) per 10 years, obtained by linear regression analysis. Trends of days with T_{max} of ≥35°C, days with T_{min} of ≥25°C, and days with T_{min} of < 0°C are significant with a 95% confidence level. The average number of days in the first 30-year period and the last 30-year period of the statistical period are also indicated.

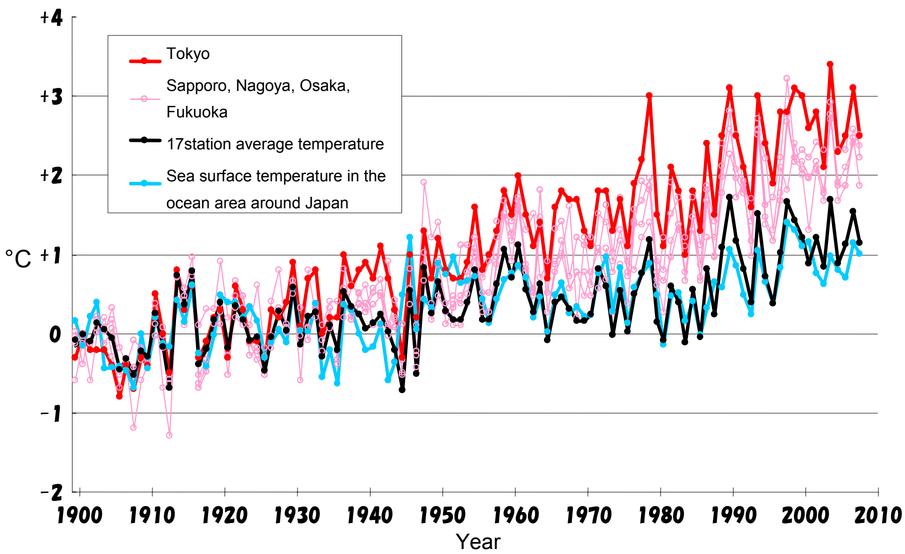
Source: JMA, 2009

[Column 3] Urban Heat Island Effect and Global Warming

Urban Heat Island effect is a phenomenon that raises urban temperatures more than suburban temperatures as a result of anthropogenic heat emissions, heat accumulation, and restraint of water evaporation and transpiration when urban ground is covered with asphalt or concrete. This effect is the cause of recent temperature rises in urban areas, in conjunction with global warming. For example, the annual average temperature rise in Tokyo is about 3°C per century. The average temperature rise in other large Japanese cities, including Sapporo, Sendai, Nagoya, Kyoto, Osaka, and Fukuoka, is more than 2°C per century. The temperature rise in those cities is far greater than the 17 station average temperature representing the average temperature rise in Japan attributable to global warming (1.1°C). This implies that the heat island phenomenon is causing a temperature rise equivalent to or surpassing the level attributed to global warming.

On the other hand, there are stations where urbanization has had little influence on temperature change. It is known that a positive correlation exists between the urbanization rate[18] and the trend of temperature rises in the data taken at observation stations across the country. Therefore, 17 stations with relatively little effect from urbanization and other environmental changes were selected when estimating the average temperatures in Japan after evaluating their urbanization rate and the continuity of observation data. The increase in sea surface temperatures in the oceans surrounding Japan, which is unrelated to the heat island phenomenon, is about 1°C per century, or roughly equal to the of average temperature increases obtained from those 17 stations. This indicates that these are appropriate for use in monitoring global warming and the natural climate variability, as the stations are little affected by urbanization.

With regards to the urban heat island effect on calculations of global average temperatures, IPCC AR4 states that urban heat island effects are real but local, and have not biased the large-scale trends (temperature increase is less than 0.006°C per decade on land and zero at sea).



Time series of large cities, 17-station average, and sea surface temperature in the oceans area around Japan

The 17-station average temperature is calculated from stations in Fig. 3.1.1. All values are annual average anomalies from the 30-year average from 1901 to 1930. Source: JMA

[18] Evaluated by the ratio of land use types such as areas of buildings, arterial traffic, and other land use existing within a 7 km radius of the observation station. Land use types are taken from the land use mesh categories of Japan's digital national land information. "Area of other use" includes areas used for athletic fields, airports, horse racing tracks, baseball grounds, schools, harbors, and open lots for land development.

(2) Changes in precipitation

The annual precipitation in Japan varies largely from year to year, and no clear trends of increases or decreases have been observed. On the other hand, the number of heavy precipitation days, such as days with daily precipitation of ≥ 100 mm or 200 mm, has been increasing over a long period, and suggests the possibility of influence from global warming.

According to the global mean precipitation ratio relative to the base period taken from the records on land only, considerable wet periods[19] were seen in the 1950s and 1990s, but no significant trend over the long-term is identified (Fig. 3.1.5).

The trend of precipitation varies greatly from region to region. It has been reported that long-term trends of precipitation were observed in many regions during the period from 1900 to 2005. Noticeable increases in precipitation were observed in the eastern regions of both North and South America, northern Europe, northern Asia, and central Asia, while aridification was observed in some areas of the Sahel region[20], the Mediterranean Sea region, southern Africa, and South Asia. Spatial and temporal variations of precipitation are very large and no conspicuous long-term trend has been observed in regions other than the above (Fig. 3.1.6). With regards to East Asia including Japan, no long-term trend is found although heavy precipitation period for several years in the 1950s.

From the annual precipitation changes in Japan, it is known that heavy precipitation occurred in the years up to the mid-1920s and also around the 1950s, but annual variations have gradually increased since the 1970s (Fig. 3.1.7).

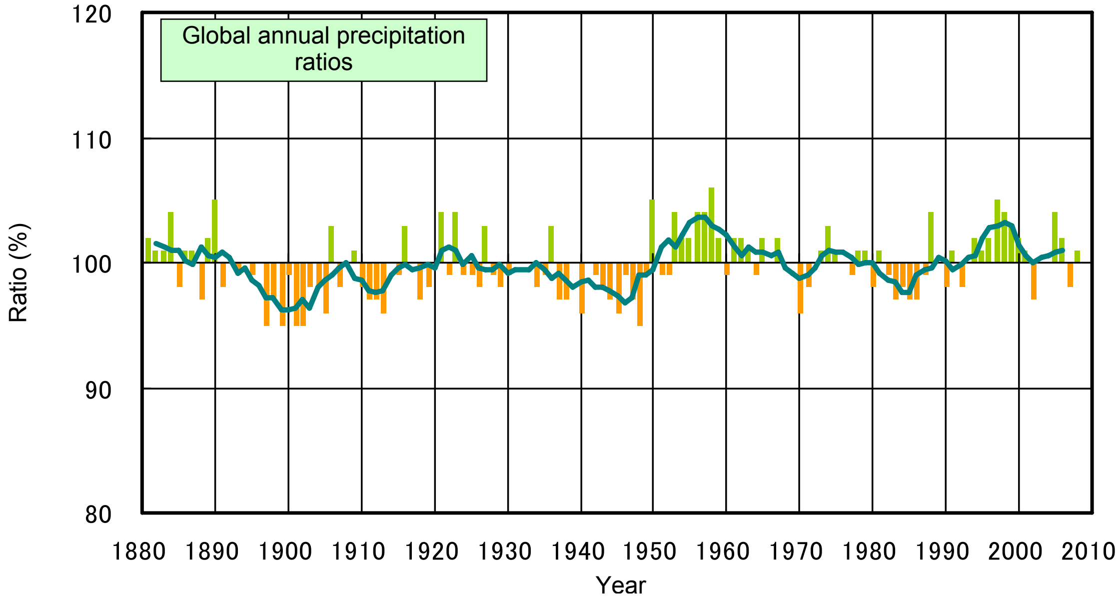


Fig. 3.1.5 Global annual precipitation ratios from 1880 to 2008

The bar represents the ratios of annual precipitation ratio to the normal (i.e. the 1971 – 2000 average). The heavy line (green) indicates the five-year running mean.

Source: JMA, 2009

19 Global mean precipitation ratio relative to normal are estimated from the data taken at the observation stations on land. First, derive the percentage of annual precipitation relative to normal (the value obtained by dividing the annual precipitation by the base period value) at each observation station. Then, average the percentage value in each 5° latitudinal × and 5° longitudinal grids on the surface Next, average the total values of all grids considering areal weight varying by latitude to each grid, to derive global average precipitation anomalies relative to normal.

20 "Sahel" means a rim in Arabic and indicates the southern rim area of the Sahara Desert. It is a semi-arid area with a small precipitation of 100 to 600 mm which varies from year to year.

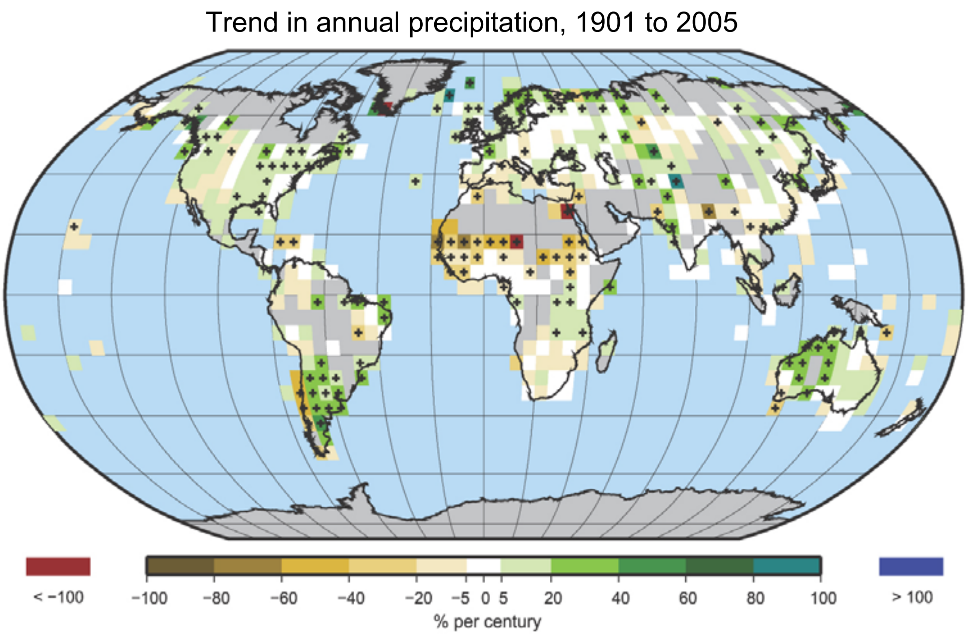


Fig. 3.1.6 Distribution of linear trends of annual land precipitation amounts over the period 1901 to 2005 (% per century)

Source: IPCC, 2007

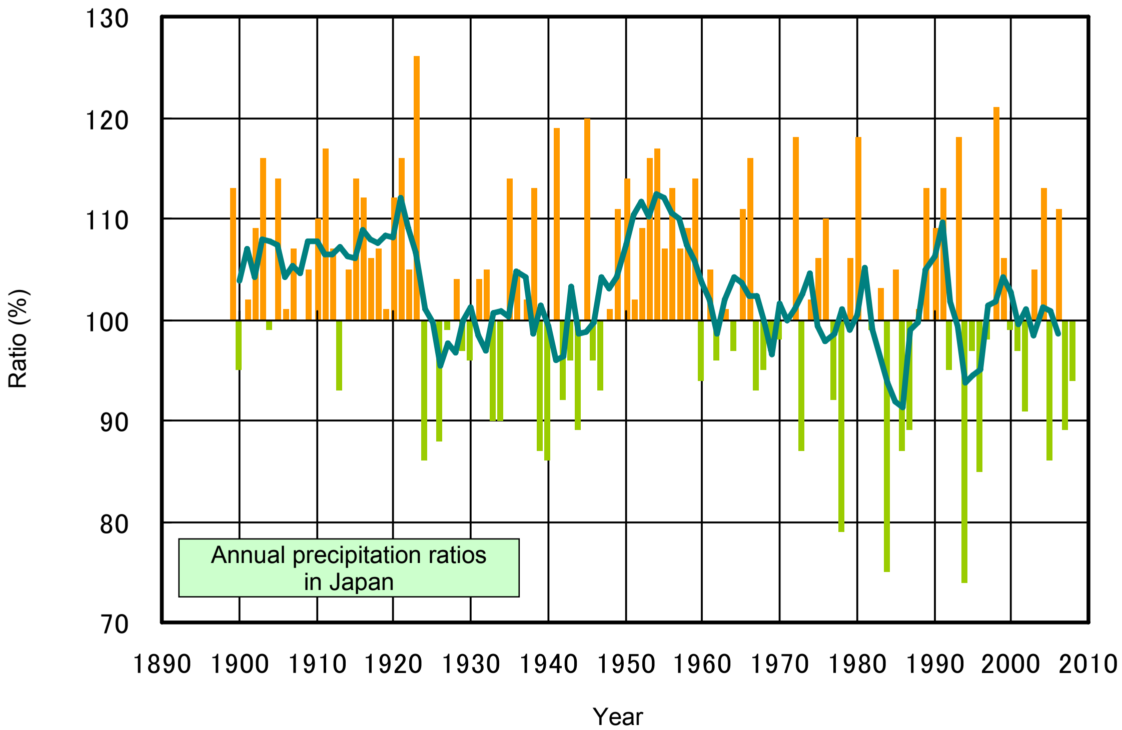
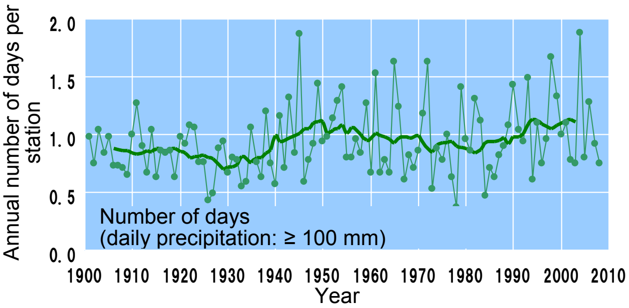


Fig. 3.1.7 Annual precipitation ratios from 1898 to 2008 in Japan

Changes in annual precipitation ratio taken at 51 stations (Fig. 3.1.1) in Japan are shown. The bar graph represents annual precipitation ratios to the normal (i.e. the 1971 – 2000 average). The heavy line (green) shows the five-year running mean.

Source: JMA, 2009

On the other hand, the number of days with a heavy precipitation of ≥ 100 mm per day and ≥ 200 mm per day shows a significant long-term increasing trend (Fig. 3.1.8, Table 3.1.4). From a comparison of the 30-year period at the beginning of the 20th century and the recent 30-year period, it is found that the number of days with ≥ 100 mm precipitation increased by about 20% and the number of days with ≥ 200 mm precipitation by about 40%. IPCC AR4 provided a view that the frequency of heavy precipitation was likely[21] to have increased in the latter half of the 20th century in most regions in the world, a similar trend seen in the increased number of days with heavy precipitation in Japan. The same report added that it is very likely that the frequency of heavy precipitation will further increase based on the results of a future projection using a scenario with an increase in GHG concentrations. This suggests the possibility that the increasing trend of heavy precipitation in Japan has occurred under the influence of global warming.



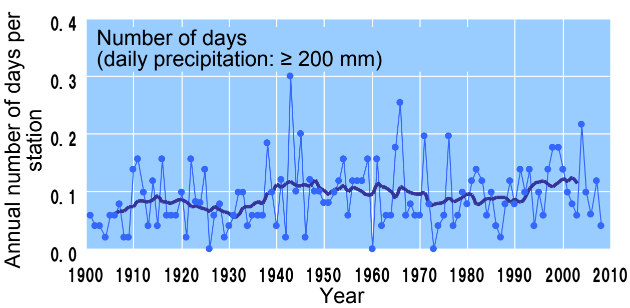


Fig. 3.1.8 Changes in the annual number of days with a daily precipitation of ≥ 100 mm (left) and ≥ 200 mm (right)

The annual number of days per station derived from the number of occurrence days at 51 stations (Fig.3.1.1). The thin and heavy lines show annual values and the 11-year running mean values, respectively.
Source: JMA, 2009

Table 3.1.4 Long-term trend in the annual number of days with daily precipitation of ≥ 100 mm and ≥ 200 mm in Japan

Number of days with precipitation of ≥ 100 mm		
Trend: +0.02 day/10 years (significant)	Average number of days from 1901 to 1930	0.84 day
	Average number of days from 1979 to 2008	1.03 days
Number of days with precipitation of ≥ 200 mm		
Trend: +0.004 day/10 years (significant)	Average number of days from 1901 to 1930	0.07 day
	Average number of days from 1979 to 2008	0.10 day

Trend of the annual number of days per station which were obtained from the occurrence days at 51 stations in Japan (Fig. 3.1.1). Statistical period: 108 years from 1901 to 2008. The trend (inclination) is represented by the number of days per 10 years derived by linear regression analysis. The trend is significant with a 95% confidence level for both precipitation ratios. The average number of days in the first 30-year period and the last 30-year period of the statistical period are also indicated.
Source: JMA, 2009

[21] "Likely" means that the likelihood of occurrence is more than 66% probability. (This means that it is significant with 33% significance level based on the significance test by taking into account the uncertainties of natural variability and climate models.)

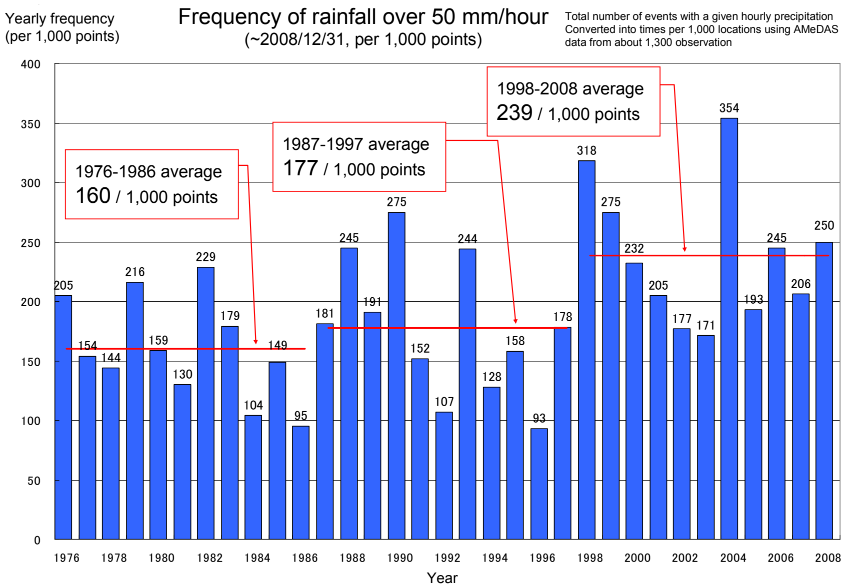
[Column 4] Frequency of Short-term Heavy Precipitation and Global Warming

It rained very heavily in a short period of time when "the torrential rains at the end of August 2008" hit the Tokai and Kanto regions on August 26 through 31, 2008. The heaviest hourly precipitation amounts were recorded in more than 20 stations, including an hourly precipitation of 146.5 mm recorded in Okazaki City, Aichi Prefecture on August 29. In addition to this event, heavy precipitation event occurred in various parts of the country from late July to early September that year. Those rains caused river flooding, swollen river accidents, and sewerage accidents, which led to an increased awareness for preventive measures as well as a concern over the possible relationship with global warming.

The annual number of short-term heavy precipitation events with an hourly precipitation of more than 50 mm and more than 80 mm, recorded by the AMeDAS system at about 1,300 observation stations across the country, has been on the rise over the past 30 years, although annual variations are considerable.

Concerning the relationship between heavy precipitation and global warming, IPCC AR4 reported that "the frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapour." (observation) based on the evaluation using daily precipitation observations. It then offered the view that "It is very likely that hot extremes, heat waves and heavy precipitation events will continue to become more frequent." (projection) An increasing long-term trend of daily precipitation amounts in Japan is consistent with this view of IPCC and it is likely to have occurred under the influence of global warming.

On the other hand, looking at short-term heavy precipitation, although it shows similar trend of the increasing frequency of heavy precipitation events which is evaluated by daily precipitation amount, we cannot deny the possibility that this trend has occurred as part of fluctuations induced by factors other than global warming, since the accumulation of hourly precipitation data is still as short as 30 years. Accordingly, we cannot conclude that the increased amount of short-term heavy precipitation is related to global warming.



Annual number of events with ≥ 50 mm hourly precipitation taken at AMeDAS observation stations (converted into number of events per 1,000 stations)
Source: JMA, 2009

(3) Tropical cyclones

No clear long-term trend has been observed concerning the number of formations, approaches, and landfalls[22] of tropical cyclones.

Atmospheric low pressure systems generated in the tropical and subtropical regions are called tropical cyclones (TCs). In the western North Pacific (range: north of the equator and west of 180°E), a tropical cyclone (TC) with maximum sustained wind speeds near the center of a tropical cyclones (10-minute average) between 17 m/s to and 25 m/s is called Tropical Storm (TS); between 25 and 33 m/s is Severe Tropical Storm (STS); 33 m/s or more is Typhoon (TY).

Figure 3.1.9 shows the number of total TS, STS and TY formations, their approaches to Japan (including the Ogasawara Islands and the Nansei Islands), and their landfalls on Japan during the period from 1951 to 2008. Although these figures show variations with different time scales, no significant long-term trends are seen. In the many of recent years, however, the number of TCs formation has been below normal.

Figure 3.1.10 describes the number of TYs formation and their ratio to the number of total TC formations (hereinafter referred to as the "ratio to formations") in the period after 1977 when the data of maximum wind speeds around the center of a TC became available. The number of TY formation varies between 10 and 20, indicating no clear long-term trend, neither increasing nor decreasing. The ratio to formations also varies between 40% and 60%, but the ratio has been around 60% in these years.

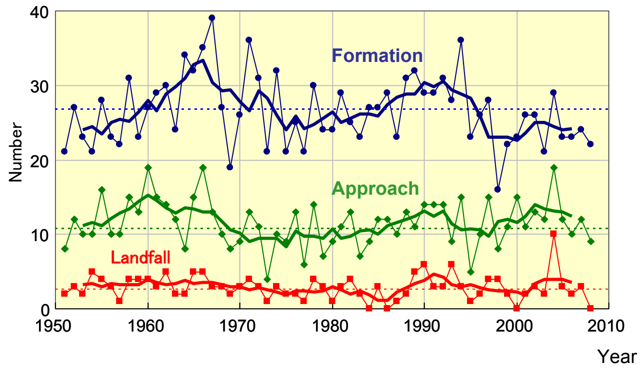


Fig. 3.1.9 The number of tropical cyclones formations, their approaches, and landfalls on Japan

The thin solid lines show the number of TCs formation (blue), those of approaches to Japan (including the Ogasawara Islands and the Nansei Islands) (green), and those of landfalls on Japan (red). The heavy solid lines give the five-year running means. The thin dashed lines show the normal values (average from 1971 to 2000).

Source: JMA, 2009

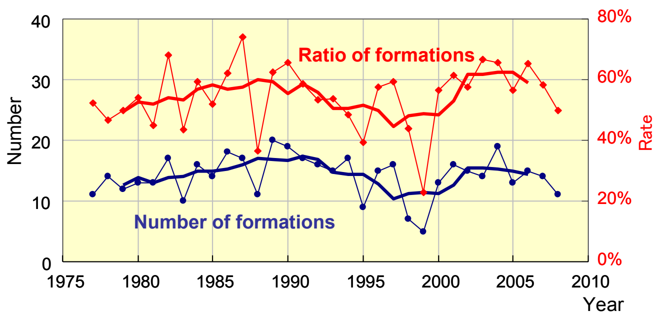


Fig. 3.1.10 The number of typhoons and their ratio to tropical cyclones

The thin lines show the changes in the number of TYs (blue) and their ratio to TC formations (red). The heavy lines give their five-year running mean.

Source: JMA, 2009

22 When the center of a TC comes within 300 km of the geographical boundaries (coast lines, prefectural boundaries, etc) of a given area, the typhoon is said to be "approaching." When the center of a TC reaches the coastal lines of Japan's main island (Honshu), Hokkaido, Kyushu, or Shikoku, the typhoon is said to have made "landfall." However, when a TC leaves for a sea after crossing a small island or peninsula, the TC is said to have made a "pass."

(4) Changes in the sea level

There is no discernible upward trend, similar to that found in the global mean sea level, in the mean sea level near the Japanese coasts over the past 100 years. The sea level near the Japanese coasts reached the highest around 1950. It also shows a marked fluctuation of near 20-year cycle.

Changes in global mean sea level since 1870 that were derived from the measurement records of sea levels in various parts of the world indicate that the global mean sea level is rising in the long-term. The global mean sea level is estimated to have risen by 0.17±0.05 m over the 20th century (Fig. 3.1.11). This is likely due to thermal expansion associated with seawater warming and thawing of land ice, including glaciers, ice caps, and ice sheets[23] in Greenland and the Antarctic region. Of the 3.1±0.7 mm sea level rise per year between 1993 and 2003, 1.6±0.5 mm is estimated to be due to thermal expansion and 1.2±0.4 mm due to the thawing of land ice.

In contrast to such rise in global mean sea level, no clear increasing trend is found in the mean sea level around the Japanese coasts over the past 100 years. The sea level near the Japanese coasts reached the highest around 1950 and is characterized by marked changes with near 20-year cycle (Fig. 3.1.12). The amplitude of annual mean sea level variation from 1906 to 2008 was about 0.12 m, which is equivalent to about two-thirds of the rise of the global mean sea level. This periodic variation predominant in the sea level around Japanese coasts is considered to be primarily due to the intensity variation and north-south shift of North Pacific westerly winds.

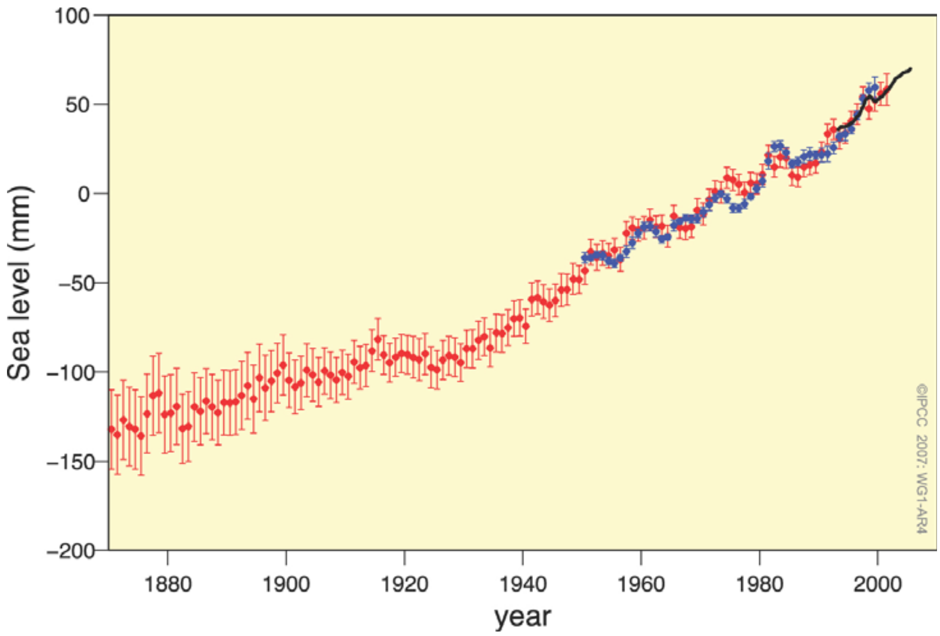


Fig. 3.1.11 Annual averages of the global mean sea level based on reconstructed sea level fields since 1870 (red), tide gauge measurements since 1950 (blue) and satellite altimetry since 1992 (black). Units are in mm relative to the average for 1961 to 1990. Error bars are 90% confidence intervals.
Source: IPCC, 2007

23 A glacier is a permanent mass of ice formed by heavily accumulated snow on land and moved by the force of gravity. An ice cap is a glacier covering the top of a mountain like a cap and having an area of less than 50,000 km^2. An ice sheet is a glacier covering an entire continent and having an area of 1 million km^2 or more. Today, ice sheets exist only in Greenland and the Antarctic Continent.

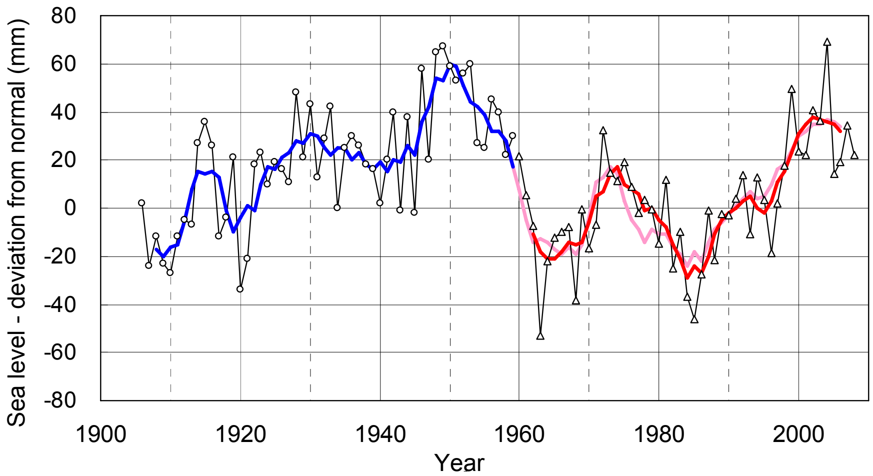


Fig. 3.1.12 Changes in annual mean sea level in Japan (1906 to 2008)

The data from 1906 to 1959 shows the annual average of anomaly taken at four tide gauge stations: Oshoro, Wajima, Hamada, and Hososhima. The data after 1960 is the annual mean of anomaly taken at four sea areas having similar variation patterns: Coastal areas in Hokkaido and Tohoku region, in Kanto and Tokai region, in the Pacific side of Kinki to Kyushu region, and in Hokuriku to the East China Sea side of Kyushu region. The normal is the mean from 1971 to 2000. The blue solid line shows the five-year running mean of annual mean anomaly of the data taken at the four tide gauge stations. The red solid line gives the five-year running mean of annual mean anomaly of the data taken at the four sea areas. The pink line shows the five-year running mean of annual mean anomaly of the data taken at the four tide gauge stations for the period after 1960, which is presented for reference.

Source: JMA, 2009

(5) Ocean Acidification

In the ocean areas to the south of Japan, the CO_2 concentration is increasing over time in the zone between the sea surface and its intermediate layer, and ocean acidification is advancing noticeably.

About 30% of the CO_2 emitted into the atmosphere after the Industrial Revolution has been absorbed by the oceans. Seawater is slightly alkaline with a hydrogen ion concentration measure (pH)[24] of about 8, but it begins to acidify if CO_2 is dissolved into it, causing a reduction in its pH. This is the process of "ocean acidification." It is estimated that surface ocean pH is already about 0.1 unit lower than pre-industrial values. Ocean acidification is said to exert a serious effect on the marine ecosystem, regardless of whether it be in a coastal area or in an open ocean area. This problem has been drawing attention as "The other CO_2 problem" in recent years.

In the ocean area along 137°E (7°N to 33°N) to the south of the Kii Peninsula where oceanographic observations have been continued for years, the CO_2 concentration in the surface seawater in winter has been increasing since 1984 when the observations started. The average rate of increase during the 25 years up to 2008 is +1.6±0.2 ppm/year (± shows a 95 % confidence interval). This is roughly equal to the rate of increase of atmospheric CO_2 concentration in this area, which is +1.7±0.1 ppm/year (Fig. 3.1.13). The total concentration of carbonic acid substances (total carbon concentration) within the ocean has also been showing an increasing trend since 1994 when the observations started. For example, in the ocean area around 30°N immediately south of the Kuroshio Current, the total carbon concentration is increasing at a rate of +1.0±0.2 μmol/kg/year[25] near the she surface.

[24] A measure of the acidity or alkalinity of an aqueous solution. An exponent showing the hydrogen ion concentration. pH 7 means it is neutral. The pH of the ocean is about 8, mildly alkaline.

[25] μmol/kg/year: A unit for expressing the increasing rate of concentration. It indicates the amount of a substance which increases in 1 kg seawater per year using the unit of 1 mol/million. The mol is a unit to show the amount of a substance using the number of particles that constitute a substance, such as elements and molecules.

It is also increasing at the rate of +0.7±0.3 μmol/kg/year to +1.5±0.2 μmol/kg/year even at a depth of 800m, although the rate of increase varies depending on the density of the seawater.

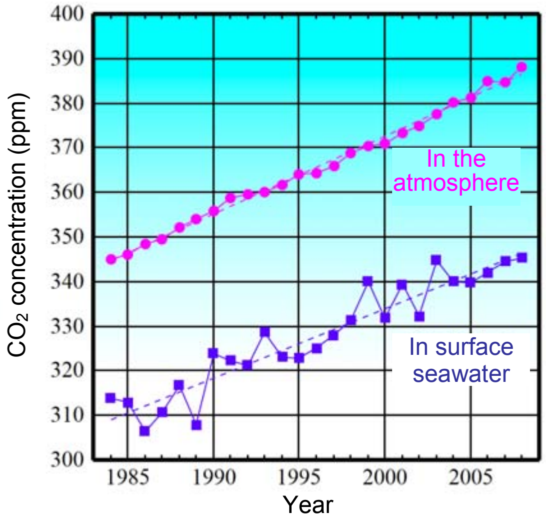


Fig. 3.1.13 Long-term changes in CO_2 concentrations in surface seawater and the atmosphere in winter in the ocean area along 137°E (mean in the range of 7 to 33° N)
Source: JMA, 2009

From the long-term changes in the pH of seawater (at the in-situ seawater temperature) estimated from the CO_2 concentration and total carbon concentration in seawater which are being observed in the ocean area along 137°E, it is found that the pH of surface seawater is significantly decreasing in all areas in the range of 7°N to 33°N (Fig. 3.1.14). The decrease per decade is -0.018±0.002 in winter and -0.013±0.003 in summer in terms of the mean of the entire areas along those latitudes. Even in the ocean from surface to 800 m depth, the pH estimated from long-term changes in total carbon concentrations and other factors is decreasing. The decreasing rate in the ocean area around 30°N is -0.013±0.005 to -0.029±0.003 per decade.

The progress of ocean acidification in the surface seawater and in the deeper ocean has been confirmed from those calculations and from pH observations that have been conducted in those ocean areas since 2003. Ocean acidification is considered to have an effect on the organisms such as shellfish and corals which form their calcareous shells and skeletons, particularly aragonites, but the research on the effects of ocean acidification on individual organism species and ecosystems began only recently. We need to deepen our understanding on ocean acidification and its effects.

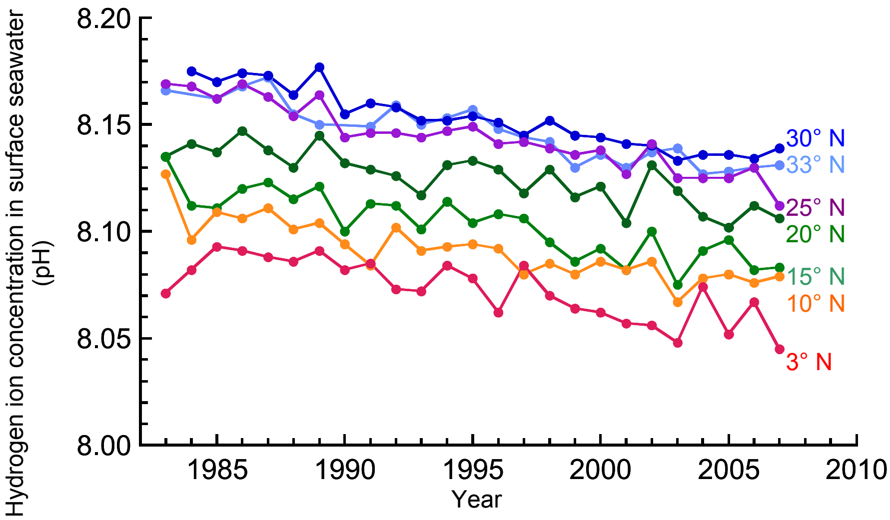


Fig. 3.1.14 Long-term changes in hydrogen ion concentration (pH) in surface seawater in winter in the ocean area along 137°E

The hydrogen ion concentration in surface seawater at each latitude is estimated from CO_2 concentration and total carbon concentration in seawater
Source: Ishii et al., 2008

3.2 Projected climate change in the future – How serious will the global warming be?

As described in Section 2.2, the change in atmospheric concentration of anthropologic GHGs is expected to have a substantial impact on climate change in the future. Emissions of GHGs depend largely on emission scenarios according to how the human and social intention and/or activities will unfold in the future. For the next 30 years or so, however, the rates of increase in GHG concentration will not vary much among the emission scenarios proposed so far, and it is after then that climate change projections begin to show differences (Fig. 3.2.3). Thus, near-term climate change projection is to be conducted based on almost the same concentration change regardless the difference in scenario (therefore sometimes referred to as near-term climate change prediction), while long-term projection is to be conducted depending on differences in scenario. The latest socio-economic scenarios, called New IPCC Scenarios, include scenarios that take policy-based emissions reduction into consideration. In these scenarios, the long-term concentration changes take very different path from those for existing scenarios.

As described above, the uncertainty in climate change projection (not for the near-term future) is firstly caused by the variety of emission scenarios. As discussed in Section 2.3, the uncertainty also arise when interactions among constituting sub-systems of the climate system, individual physical processes, and biogeochemical processes are formulated in a climate model, or in other words, the uncertainty arise in the modeling itself. Furthermore, another kind of uncertainty appears due to the inadequate representation of geography with insufficient model resolution.

Taking uncertainties among different models into account, IPCC AR4 assessed the likely range and best estimates for the projected change of the global average surface temperature up to the end of the 21st century under each of representative (marker) emission scenarios. It also shows a steady trend that the sea level rises to continue in the future. But although the likely range of the projected sea level change has become considerably narrower thanks to the advancement of models, it remains unable to specify best estimate values due to the uncertainties associated melting of ice sheets. On the other hand, the frequency or intensity of extreme meteorological events, especially heat waves, droughts, heavy rainfalls, and tropical cyclones (typhoons and hurricanes) is expected to increase with the global warming. This means that currently observed trends will further intensify in the future.

IPCC AR4 does not deal with regionally detail projections of climate change near Japan because there have not been such research results comparable in the world other than those in Japan. Nonetheless, research groups in Japan are working on projecting climates change around Japan using models such as the high-resolution coupled atmosphere-ocean model, super high-resolution global atmospheric model, and regional climate model around Japan. They have been achieving considerable results.

Based on findings in climate change projections, the following sections describe how serious global warming or warming around Japan will show, with due consideration of the uncertainty.

(1) Greenhouse gas emission scenario

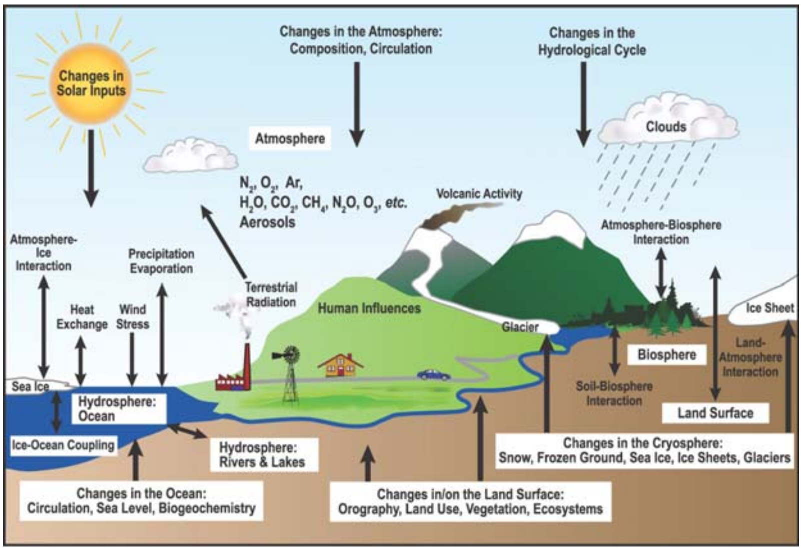
The progress of global warming largely depends on in what direction humans develop their societies. That is, different schemes of social development in the future will result in different projections for energy and land uses, thus very different emissions scenarios of GHGs.

[Column 5] Climate change projection models

Weather forecasts over the next few days such as how the weather will be tomorrow or the day after tomorrow are conducted based on the results from numerical weather prediction model. In the numerical weather prediction, a set of equations representing a Newton's dynamic law and a thermodynamic law, equation of continuity for the air mass and water vapor are numerically solved to predict changes of the weather over several days in the future from its present state. Since the prediction depends on initial conditions, it is called an "initial-value problem".

Climate change projections such as how the climate will change over the next 100 years are conducted based on a climate model (also called a climate change projection model) targeting climate, the average state of weather condition. Climate models have been developed from numerical weather prediction models. Climate is considered as a system (climate system) consisting of climate subsystems such as the atmosphere, oceans, land surface, biosphere, and cryosphere (see the figure below) and is represented by their balanced state (equilibrium state) produced through their processes (physical and biogeochemical processes) and their interactions. A climate model shows climate change based on how the climate system will respond to naturally induced driving factors such as changes in solar and volcanic activities and anthropogenic driving factors including GHG emissions and aerosol changes that follow emission scenarios depending on how humans and social trends and activities will change in the future. Unlike the weather forecasts, it is a projection of how the climate will respond to forcings, called as driving factors, and to what kind of balanced state the climate system will change, and so the response plays an essential role (thus a climate change projection can be considered as a "forced response problem"). A coupled atmosphere-ocean general circulation model is usually used as a climate model, but more simplified climate models based on energy balance and other factors have also been introduced for projections with limited targets such as projections of changes in global mean temperature and/or sea level.

On the other hand, near-term climate change projections for the next 30 years or so might depend on initial conditions; thus, they are regarded as being associated with the characteristic of an *initial-value problem* in addition to a *forced response problem*. Therefore, a climate model for near-term projections need to be capable of properly representing responses to driving factors as well as projecting short-term natural variabilities based on initial conditions.



Schematic view of the components of the climate system, their processes and interactions

Source: IPCC, 2007

The SRES scenario (IPCC, 2000) roughly divides emission scenarios into four categories: two categories (speed of economic growth: fast and slow) times two categories (level of the progress of globalization) (Fig. 3.2.1).

A: Society that emphasizes economic growth

B: Sustainable society in harmony with the environment

1: Case in which regional disparity narrows and globalization advances

2: Case in which regional uniqueness intensifies

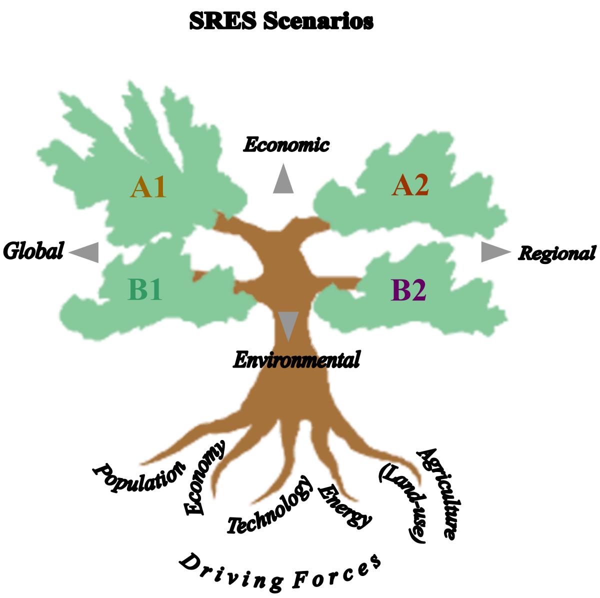


Fig. 3.2.1 Schematic illustration of SRES scenarios. The four scenario "families" are shown, very simplistically, as branches of a two-dimensional tree. In reality, the four scenario families share a space of a much higher dimensionality given the numerous assumptions needed to define any given scenario in a particular modeling approach. The schematic diagram illustrates that the scenarios build on the main driving forces of GHG emissions. Each scenario family is based on a common specification of some of the main driving forces.

Source: IPCC, 2000

The A1 scenario family is categorized into three sections based on choices of technological innovations in energy systems: emphasis on fossil energy sources (A1FI); emphasis on non-fossil energy sources, (A1T); and emphasis on a balance between all energy sources (A1B).

Projection results for the future introduced later in this report are based on A2, A1B, and B1 scenarios. The standard amount of GHG emissions in individual scenario is high in A2, low in B1, and medium in A1B (Fig. 3.2.2). The amounts of emissions shown in Figure 3.2.2 do not take aggressive measures against climate change into account. That is, all of these scenarios are so called non-mitigation scenarios that do not assume aggressive measures against climate change such as implementation of the United Nations Framework Convention on Climate Change and reduction goals of the Kyoto Protocol.

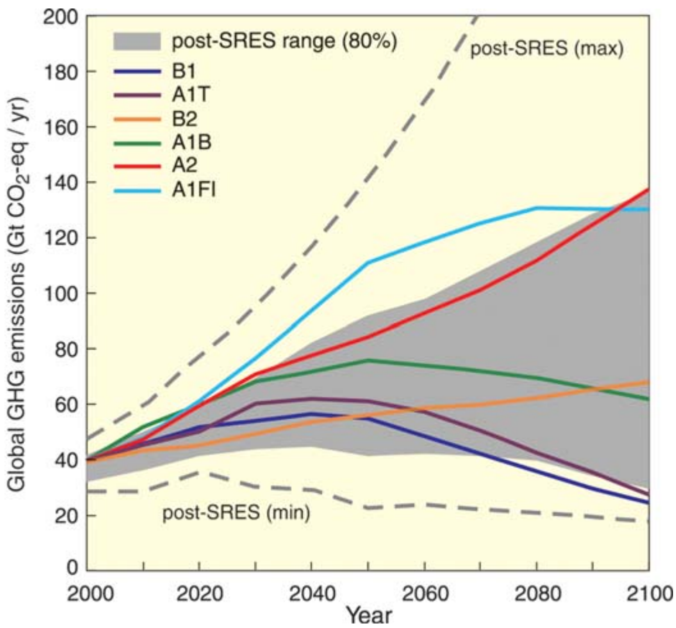


Fig. 3.2.2 Global GHG emissions (in $GtCO_2$-eq per year) in the absence of additional climate policies: six illustrative SRES marker scenarios (coloured lines) and 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions include CO_2, CH_4, N_2O and F-gases.

Source: IPCC, 2007

(2) Projection of temperature

The temperature in Japan is projected to increase as the CO_2 concentration increases, and the warming range is projected to be greater than the global average. As the temperature increases, the number of days with T_{min} of < 0°C is projected to decrease while the numbers of days with T_{max} of ≥30°C, days with T_{max} of ≥35°C, and days with T_{min} of ≥25°C are projected to increase.

The global temperature by the end of the 21st century is expected to keep increasing as the CO_2 concentration increases (Fig. 3.2.3). This projection is a summary of the results of 23 climate change projection models that research institutions around the world have developed. It shows ensemble average and the ranges of spread thereof among the multi model projections for individual GHG emissions scenarios. The temperature is projected to increase at a rate of about 0.2°C per decade over the next 20 years in all scenarios. Variations among the scenarios begin to appear after next 20 years, and the temperature is projected to increase by 1.8–4.0°C from the end of the 20th century to the end of the 21st century in the best estimate in each scenario. The warming is expected to be 1.1–6.4°C when likely estimate ranges are included.

Based on regional temperature projections around the world, the warming range will be large in land areas and most parts of high latitude regions in the northern hemisphere, and the temperature will increase more on the land than on the sea (Figure 3.2.4 shows an example of the A1B scenario).

The projected average temperatures in Japan under the A2, A1B, and B1 scenarios show that the increase by 4.0°C, 3.2°C, and 2.1°C, respectively, from the end of the 20th century (1980 to 1999) to the end of the 21st century (2090 to 2099); all scenarios indicate that the temperature will be higher than the global average (3.4°C, 2.8°C, and 1.8°C) (Fig. 3.2.5).

Detailed distribution of projections over Japan in about 100 years in the future based on a regional climate model with high horizontal resolution (Fig. 3.2.6) show varying degrees of warming in different areas, and the high latitude regions are expected to experience a greater degree of warming. The model also shows a trend in which warming are more prominent in winter than in summer.

With such warming in the future, the numbers of days with T_{min} of < 0°C and days with T_{min} of ≥25°C are expected to change as well. Based on the projection of the numbers of such days produced using temperature projections in multiple climate models, the number of days with T_{min} of < 0°C over Japan 100 years from now is projected be 25 to 38 days fewer for each scenario (Fig. 3.2.7). The decrease is especially prominent in mountainous regions in Honshu, the Tohoku region, and Hokkaido; the number of days with T_{min} of < 0°C is projected to decrease by 50 days or more in the Pacific and the Okhotsk sides of Hokkaido (Fig. 3.2.8: projection result of the A2 scenario that uses a single regional climate model). Conversely, the decrease in the number of days with T_{min} of < 0°C is smaller in warmer regions that originally had fewer winter days such as Kyushu.

The number of "hot days" such as days with T_{max} of ≥30°C, days with T_{max} of ≥35°C and days with T_{min} of ≥25°C is expected to show large increases especially in the Kanto region and the area south of and including the Kinki region.

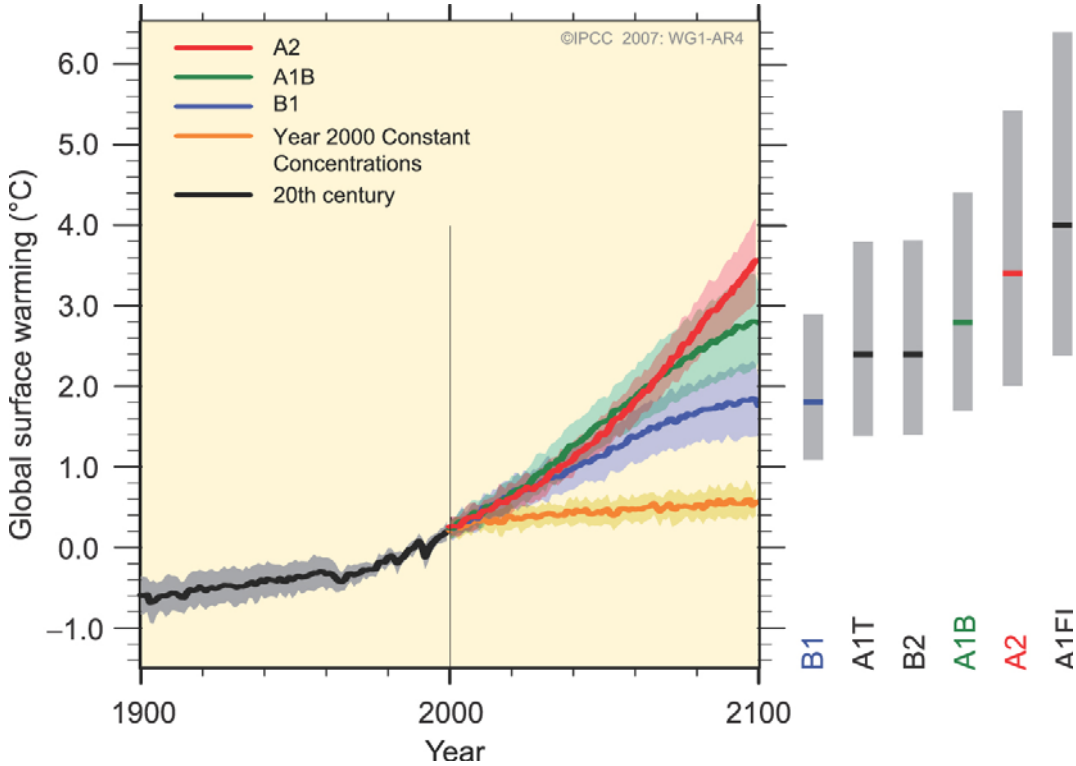


Fig. 3.2.3 Projected global average temperature

Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios. The assessment of the best estimate and likely ranges in the grey bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints.

Source: IPCC, 2007

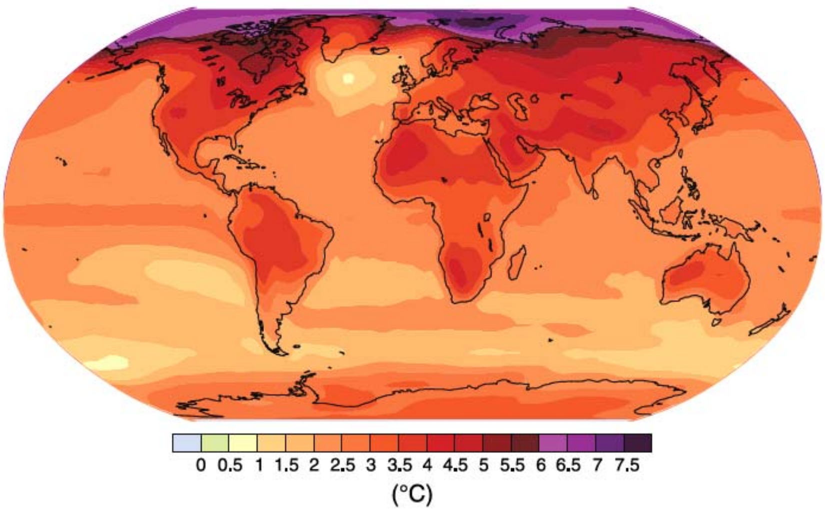


Fig. 3.2.4 Projected surface temperature changes for the late 21st century (2090-2099)

The map shows the multi-AOGCM average projection for the A1B SRES scenario. Temperatures are relative to the period 1980-1999.

Source: IPCC, 2007

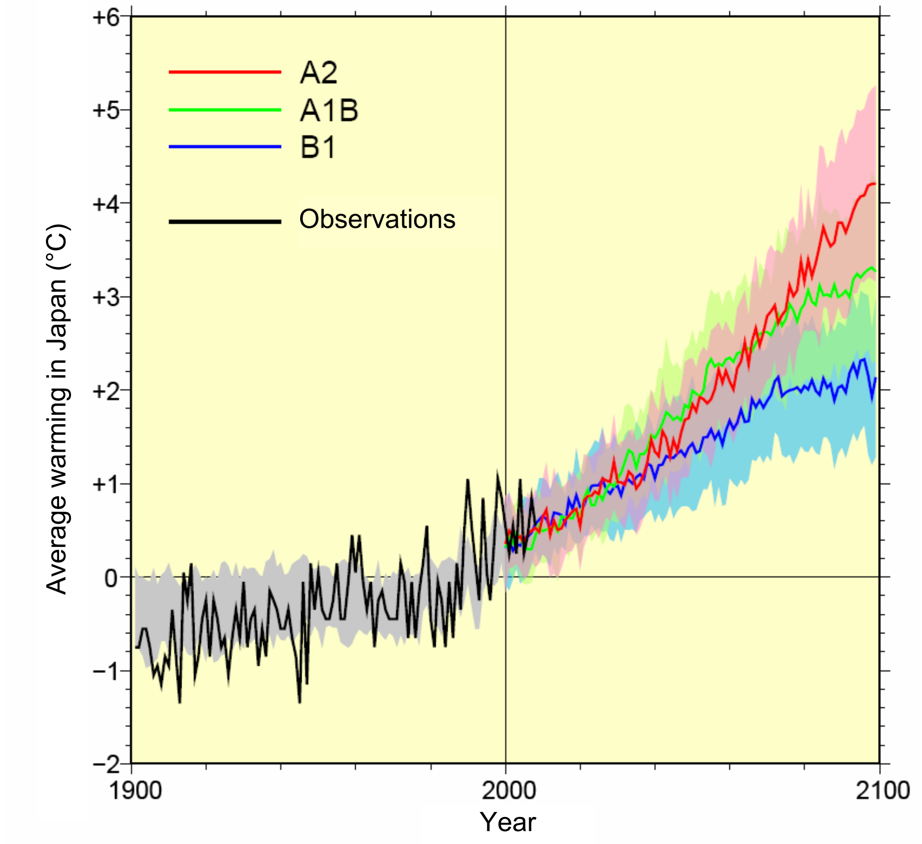


Fig. 3.2.5 Projected average temperature in Japan

The graph shows the result of average temperature in Japan under A2, A1B, and B1 scenarios on multiple climate models used in IPCC AR4. Of the grids of individual models, grids in which Japan's land coverage is 30% or more were selected, and the averages of the values in the grids were used as Japan's projected temperature of individual models. The averages and projected range (±standard deviations) in individual scenarios are shown in red, green, and blue solid lines and shadows. The black line indicates observed average temperature in Japan (Fig. 3.1.3). The shadow before 2000 indicates the simulated range of the past (±standard deviation). It is shown based on the difference from the 20-year average value from 1980 to 1999.[26]

Source: JMA

[26] The current climate model may have inferior reproducibility for regional changes that are smaller than continent levels and extreme events. The average temperature of Japan in the first half of the 20th century is reproduced slightly higher than observed temperatures.

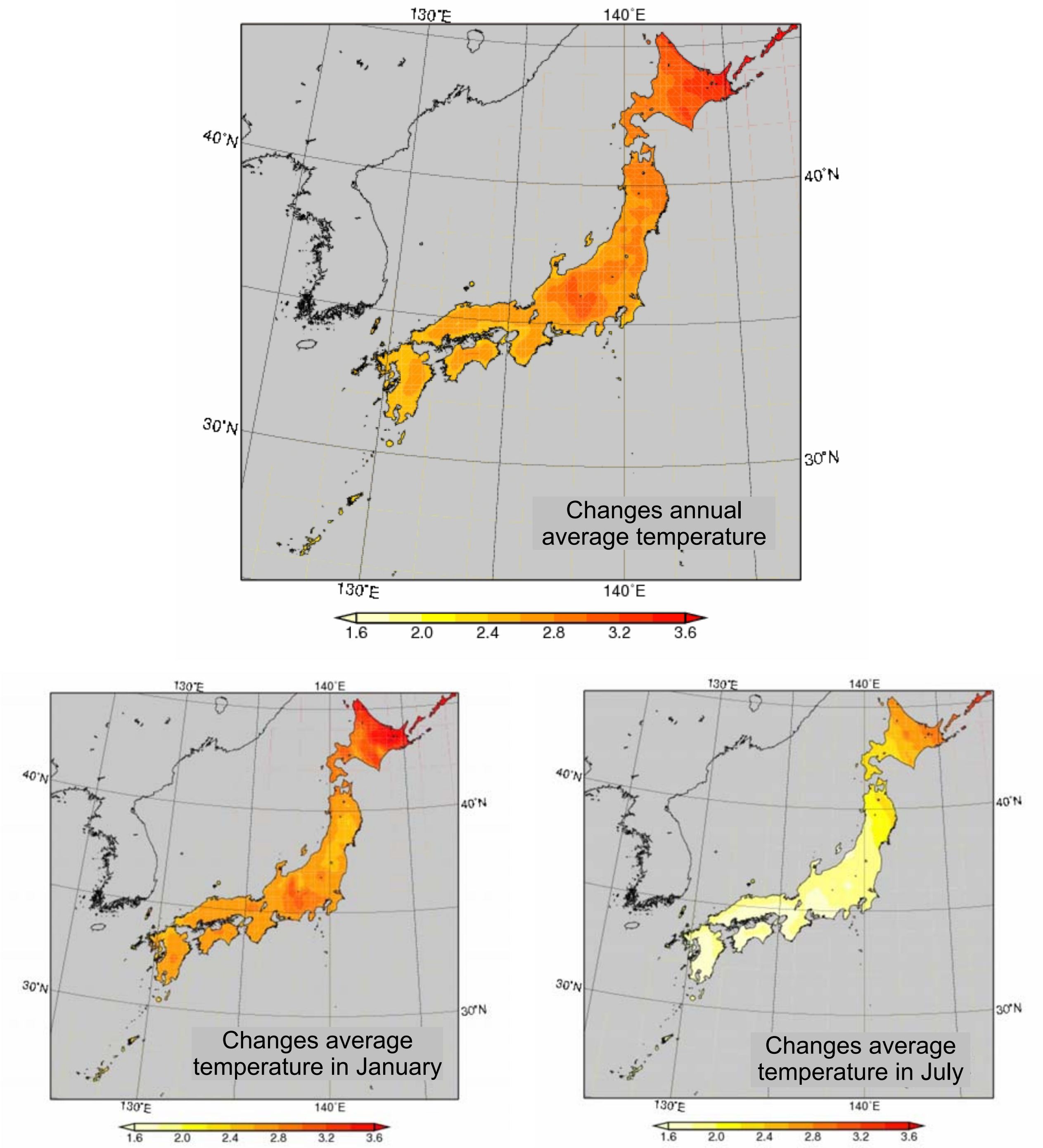


Fig. 3.2.6 Regional temperature changes in Japan (°C)

These maps shows projected changes in annual average temperature (above), average temperature in January (below left), and average temperature in July (below right). They show differences in the 20-year averages between 2081 and 2100, relative to between 1981 and 2000. These are projected results of the A2 scenario based on a regional climate model with horizontal resolution of 20 km (RCM20). These calculations were obtained based on a single model, and using different models may produce different calculation results. The reliability of temperature projections is low around the Sea of Okhotsk and near the Seto Inland Sea, due to the characteristics of the global climate model given as a boundary condition and problems associated with calculating regional climate models.

Source: Produced based on JMA, 2005b

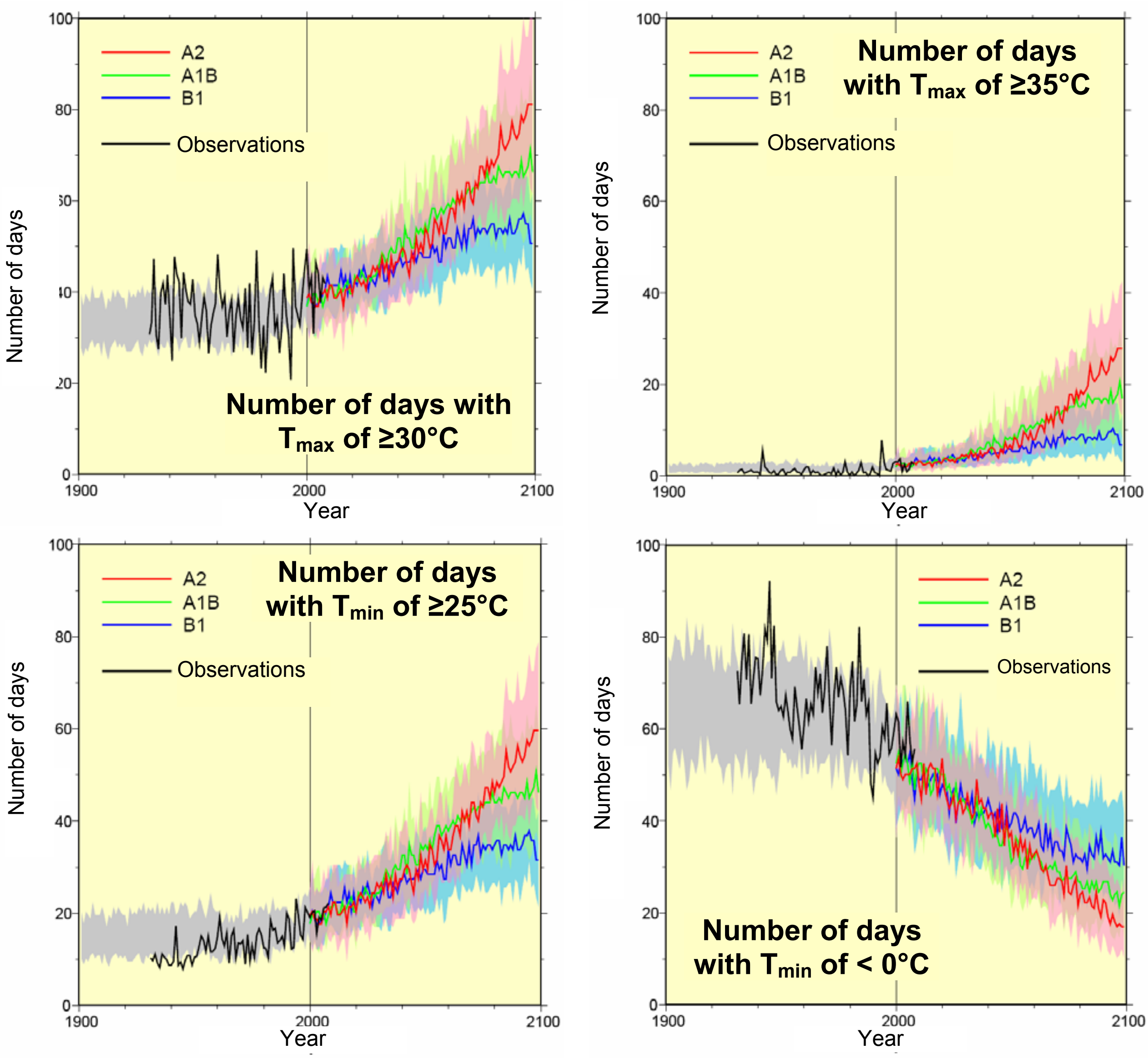


Fig. 3.2.7 Projection of the annual number of days with T_{max} of ≥30°C (upper left), days with T_{max} of ≥35°C (upper right), days with T_{min} of ≥25°C (lower left), and days with T_{min} of < 0°C (lower right)

These show changes in the annual number of days per station calculated based on temperature data in 15 stations used in calculating the number of days with T_{max} of ≥30°C etc. in Japan (Fig. 3.1.4) and temperature projection of the A2, A1B, and A2 scenarios under multiple climate models used in IPCC AR4. The numbers of days were calculated by adding average temperature changes (difference from the 10-year average from 1990 to 1999) in summer (August) and winter (January) in Japan, which were calculated in climate projection models, to the daily maximum or minimum temperatures at each station from 1990 to 1999. The red, green, and blue lines and shadows indicate the averages and projected range (± standard deviation) under individual scenarios. The black line indicates observed values (Fig. 3.1.4). The shadows before 2000 indicate the simulated ranges of the past (± standard deviation).

Source: JMA

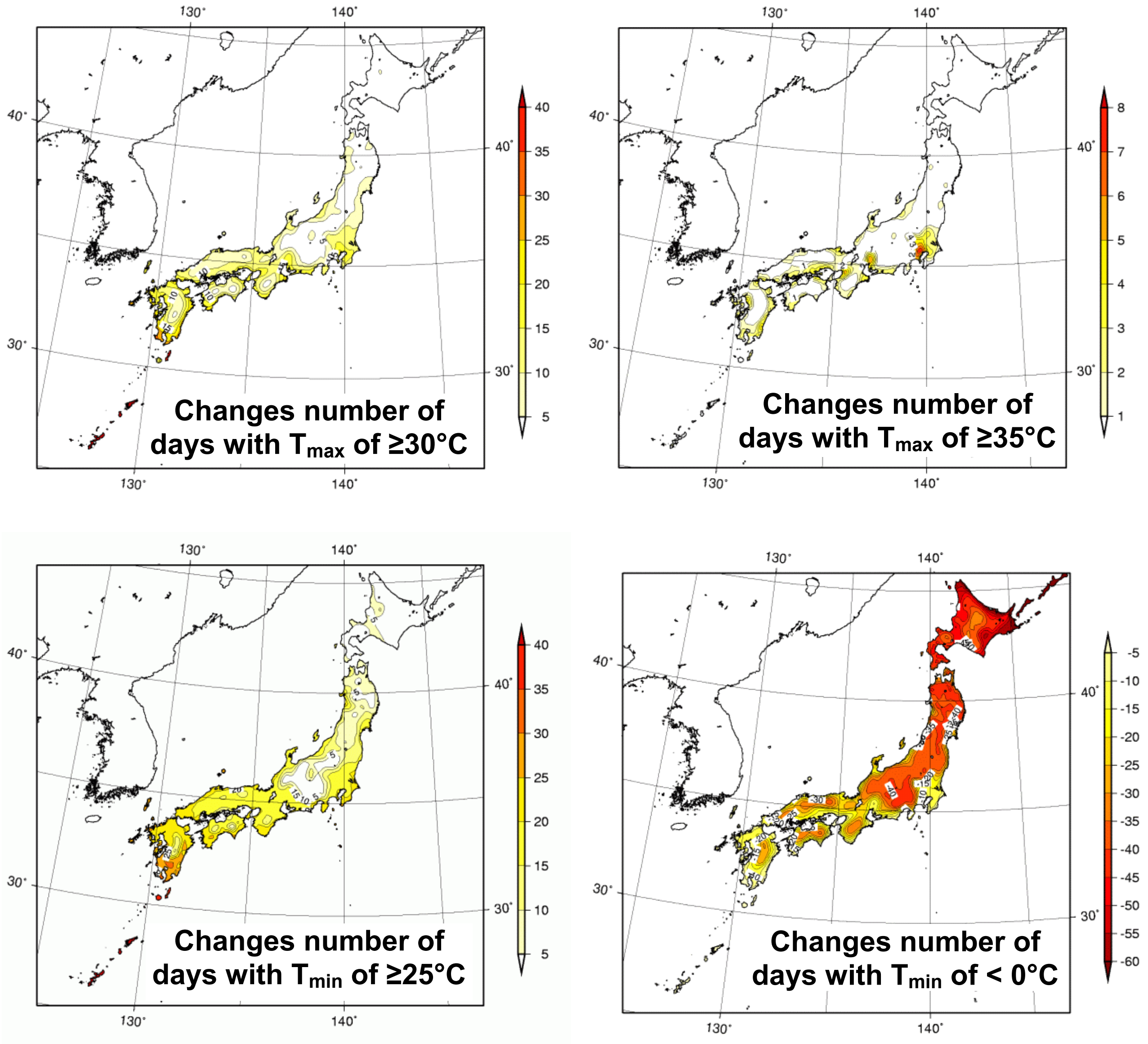


Fig. 3.2.8 Changes in the annual number of days with T_{max} of ≥30°C (upper left), days with T_{max} of ≥35°C (upper right), days with T_{min} of ≥25°C (lower left), and days with T_{min} of < 0°C (lower right) in Japan (days)

The maps show the difference in 20-year averages from 2081-2100, relative to the 1981-2000 average. These are projection results under the A2 scenario based on a regional climate model with a horizontal resolution of 20 km (RCM20). These are based on a single scenario with a single model, and results may vary if a different model or scenario is used.

Source: JMA, 2005b

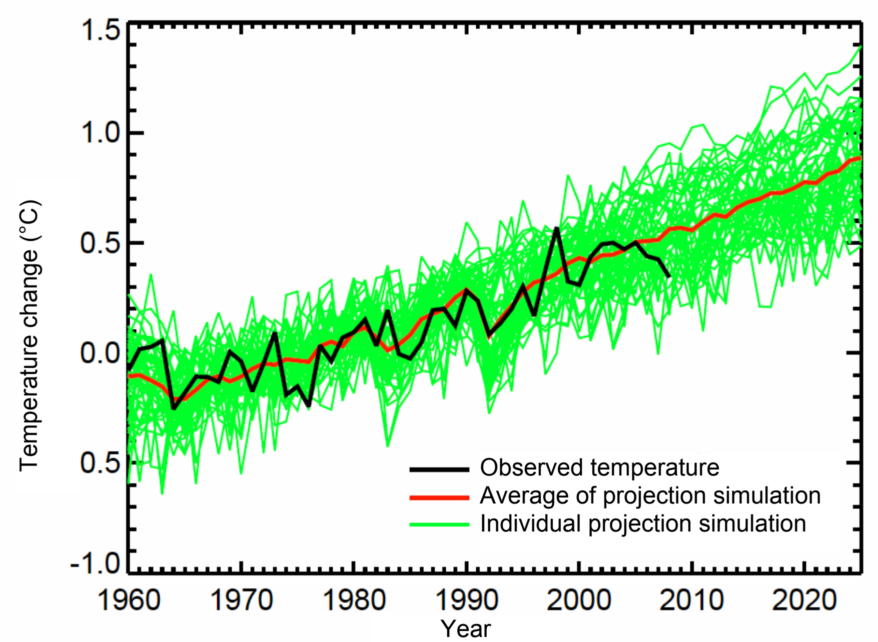
[Column 6] Trend of the recent global average temperature

The global average temperature has been high since the mid-1990s; it has been 0.15 to 0.32°C higher than normal years except in 1996 (Fig. 3.1.1). The annual anomalies of the global average temperature since 2001 are all ranked within the top 10 since records began in 1891. The annual anomaly average temperature in 2008 was 0.20°C above normal, which was the 10th largest difference on record.

Some argue that global warming has stopped or that IPCC's global warming projection was wrong because the annual average temperature in 2008 was lower than that of 2007 or 2006. However, it is too hasty to reach such a conclusion at this point.

Variations in the global average temperature are a result of long-term warming due to global warming and overlapping factors such as the El Niño and La Niña phenomena and a timeframe of several years to several decades such as Pacific Decadal Oscillation. Natural variability, La Niña and Pacific decadal variability are considered to have been the candidates for the lower temperature in 2008 in comparison to the past few years.

The climate model employed for the climate projection of IPCC AR4 successfully simulated such natural variability and made projections for global warming based on such simulation. The graph below shows individual projection based on such climate models in green, the average of all the models results is shown in red, and the observed temperature is shown in black. The warming trend and legitimacy of projections can be negated when the observed temperature (black line) shows a systematic deviation from the distribution of multiple projections (green lines). However, the observed temperature up to this point has stayed near the average of the projections (red line) and remained within the distribution of the projections shown in green; thus, the projection has been sufficiently simulating the warming trend.



Observed temperature change and projection simulation from 1960 to 2025

The graph plots the observed global average temperature produced at Hadley Centre for Climate Projection and Research in England (HadCRUT3) and simulated temperatures of multiple climate models evaluated in IPCC AR4 (World Climate Program's coupled model intercomparison project (WCRP CMIP3), multi-model dataset).

Source: NIES

(3) Projection of precipitation

Annual precipitation in Japan is expected to increase by about 5% by the end of the 21st century, in comparison to the end of 20th century. However, it is necessary to pay attention to large interannual variability, along with uncertainties of the projection. Precipitation and the number of days with heavy precipitation in summer are expected to increase with global warming.

While the temperature increases almost globally as the CO_2 concentration increases, precipitation will increase in some regions whereas it will decrease in other regions. In terms of such regional variations, in some areas different trends are projected among climate models, but in other areas many models indicate consistent trends. IPCC AR4 has assessed such projections of global precipitation distribution and projected that precipitation will very likely increase in high-latitude regions, whereas it is likely to decrease in most parts of subtropical lands (Fig. 3.2.9).

A projection of annual precipitation in Japan indicates an increase by about 5% by the end of the 21st century in comparison to the end of the 20th century. However, it is necessary to understand that this projection is associated with large interannual variations as well as uncertainties of projections (Fig. 3.2.10).

According to a projection of regional precipitation in Japan produced by a regional climate model with a high horizontal resolution (projection under the A2 scenario with a single model), the annual average precipitation will increase in most parts of Japan in the end of the 21st century, although it is expected to decrease in some parts of southern Kyushu (Fig. 3.2.11). The number of days with heavy precipitation on which daily precipitation reaches 100 mm or more is expected to increase in many areas except southern Kyushu.

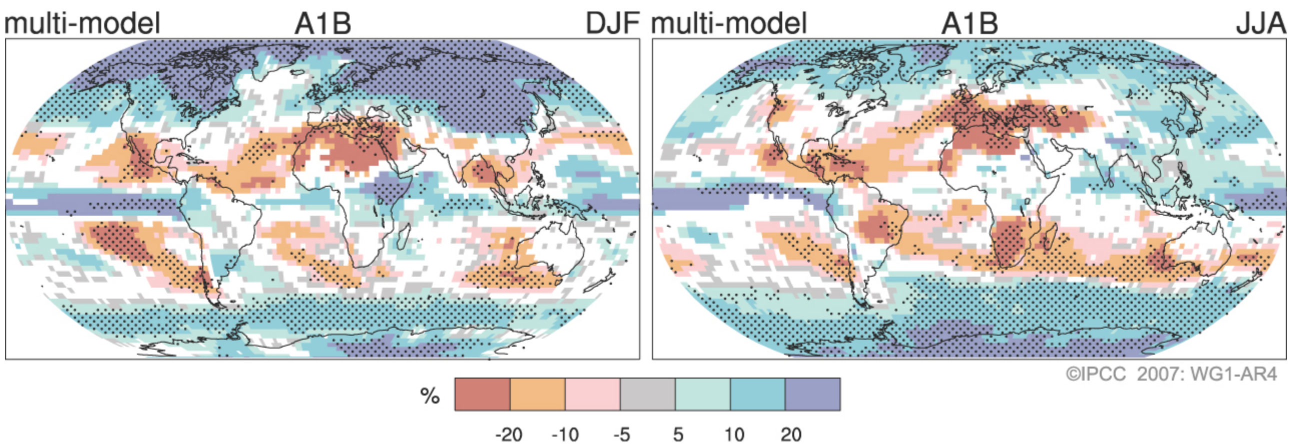


Fig. 3.2.9 Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change.
Source: IPCC, 2007

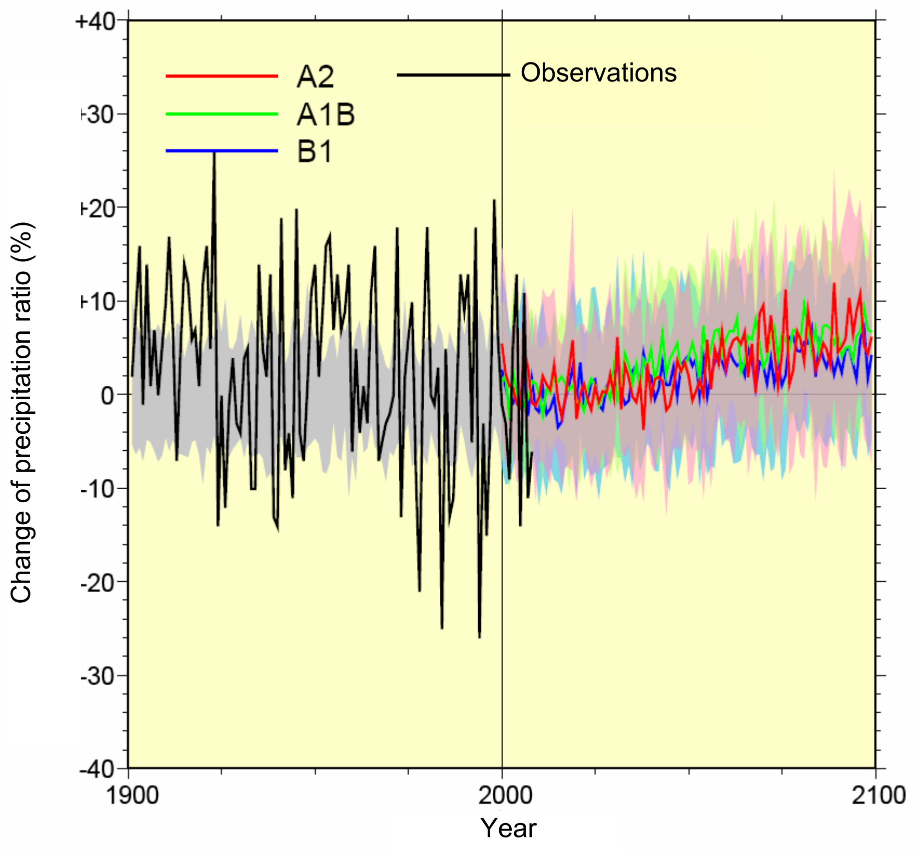


Fig. 3.2.10 Projection of annual average precipitation in Japan

The annual average precipitation in Japan under the A2, A1B, and B1 scenarios that use multiple climate models in IPCC AR4 is shown along with observed precipitation. Grids in which Japan's land coverage accounts for 30% or more were selected from grids in individual models, and the average value of these grids are used as projected value of the annual average precipitation in Japan for individual models. Average values and range of the projections (± standard deviation) are shown in red, green, and blue lines and shadows. The black line indicates observed precipitation in Japan (Fig. 3.1.7). The shadow before 2000 indicates the range of simulation in the past (± standard deviation). The graph is shown in ratios of change from the 20-year average from 1980 to 1999.

Source: JMA

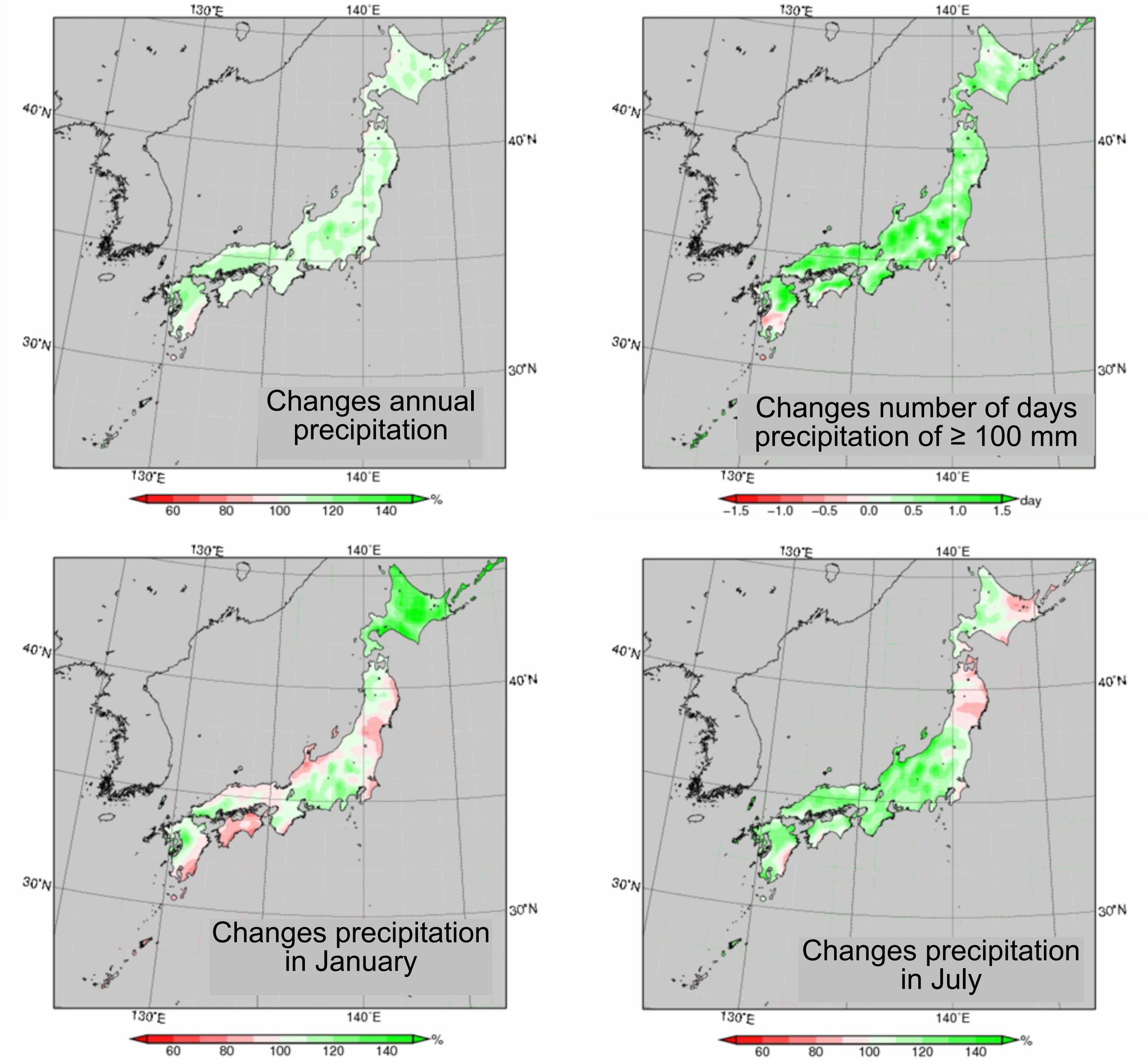


Fig. 3.2.11 Projection of change in precipitation in Japan

The maps show projected changes in annual precipitation (above left), precipitation in January (below left), precipitation in July (below right), and the number of days with precipitation of ≥ 100 mm (above right). These are comparisons between the 20-year average from 1981 to 2000 and that from 2081 to 2100. Precipitations are shown as percentages (%). These are projected results under the A2 scenario that use regional climate model of horizontal resolution of 20 km (RCM20). These are the result of a single scenario with a single model, and calculation results may differ under different models or scenarios.

Source: Produced based on JMA, 2005b

The precipitation projections for January and July shown at the bottom of Figure 3.2.11 indicate that precipitation will increase in a wide range of areas at the end of the 21st century compared to the end of the 20th century. However, the precipitation is projected to decrease in some parts of Shikoku, Hokuriku, and Tohoku in January and some parts of northern Japan and Kyushu in July. Also, the number of days with heavy precipitation of 100 mm or more in one day in summer is projected to show a large increase because of the intensification of individual precipitation events (Fig. 3.2.12). A warming-related increase in the amount of atmospheric vapor is considered to be one of the factors for such increases in summer precipitation and the number of days with heavy precipitations. Projection based on a climate model indicates a trend that the force to push the *Baiu* front to the north will weaken and make it easy for the front to stay around Japan; thus, the offset of *Baiu* the rainy season in early summer, will be delayed.

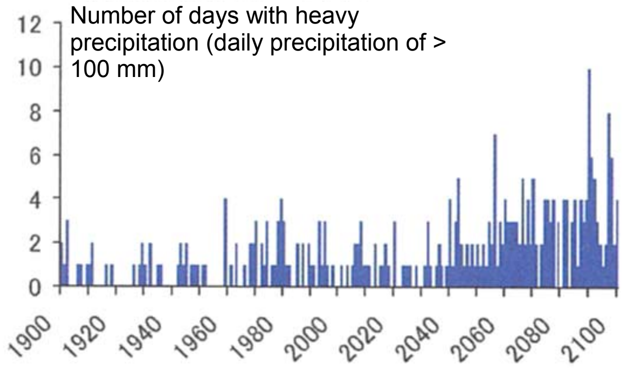


Fig. 3.2.12 Number of days with precipitation of > 100 mm per day in summer in Japan (June to August)

The graph shows the number of days on which daily precipitation exceeds 100 mm in at least one grid (about 100 × 100 km) that covers the Japan. It is based on a projection under the A1B scenario that uses a high resolution coupled atmosphere-ocean general circulation model with a horizontal resolution of about 100 km (MIROC). Since it is based on the average of a wide range of areas, its absolute value cannot be directly compared with observed data. Only relative change is important.

Source: University of Tokyo et al., 2007

According to the projection under the A1B and B1 scenarios that use a single regional climate model, the amount of snowfall will decrease in all areas except in Hokkaido (Fig. 3.2.13). A possible reason for this trend is that precipitation rather than snowfall will increase in the south of Tohoku as the climate gets warmer, whereas the climate is cold enough to result in snowfall in Hokkaido; thus, the amount of snowfall is expected to increase as the atmospheric vapor increases with the warming.

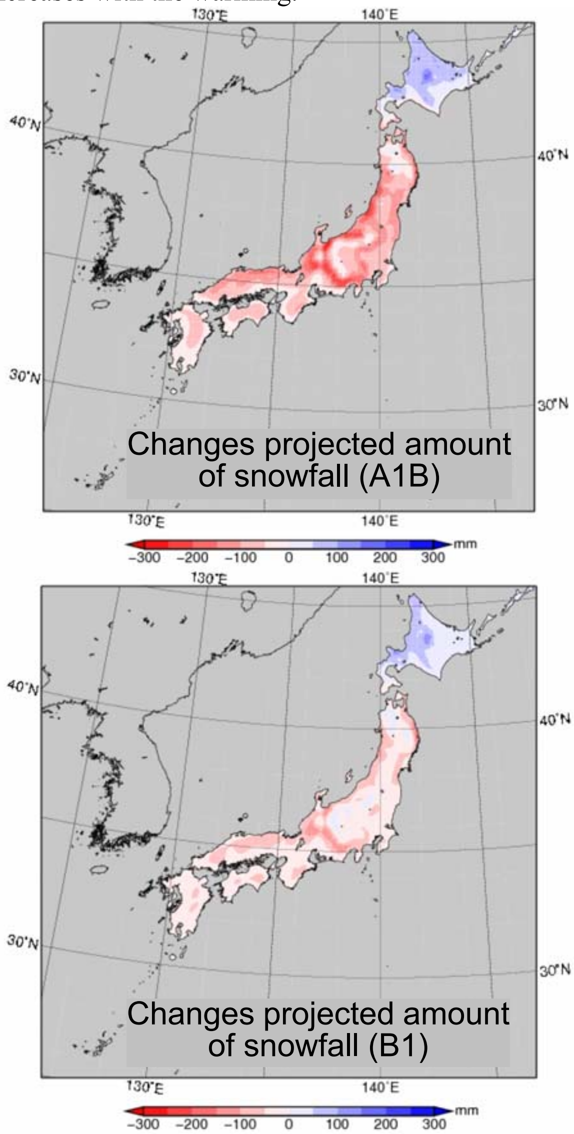


Fig. 3.2.13 Changes in the amount of snowfall in Japan

Difference in the 20-year average of the amount of total snowfall in the cold season (December to March) from 2081 to 2100 and from 1981 to 2000, which is converted into precipitation (mm). It is a projected result under the A1B scenario and the B1 scenario with coupled atmosphere-ocean regional climate models with a horizontal resolution of 20 km (CRCM20). The projection is based on single model and two scenarios; using a different model or scenario may produce a different calculation result.

Source: Produced based on JMA, 2008

(4) Projection of Tropical Cyclones

The number of extremely strong tropical cyclones is expected to increase with global warming.

The use of a high resolution global atmospheric climate model with 20 km horizontal grid resolution has enabled us to express spatial structures of a tropical cyclone such as the eye, eye wall cloud, and rain band (Fig. 3.2.14). The improved capacity of tropical cyclone simulation using a climate model has increased the reliability of projections of global warming-related changes in tropical cyclone (Fig. 3.2.15).

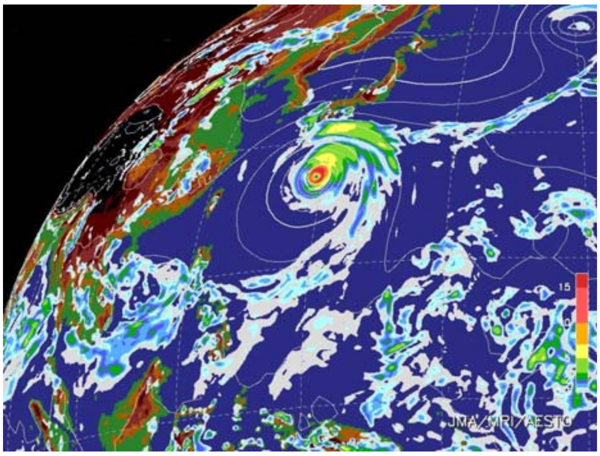


Fig. 3.2.14 Example of tropical cyclone simulated in high-resolution atmospheric global climate model

A tropical cyclone simulated in a high-resolution global atmospheric climate model with a horizontal resolution of 20 km (GCM20)

Source: Meteorological Research Institute et al. 2007

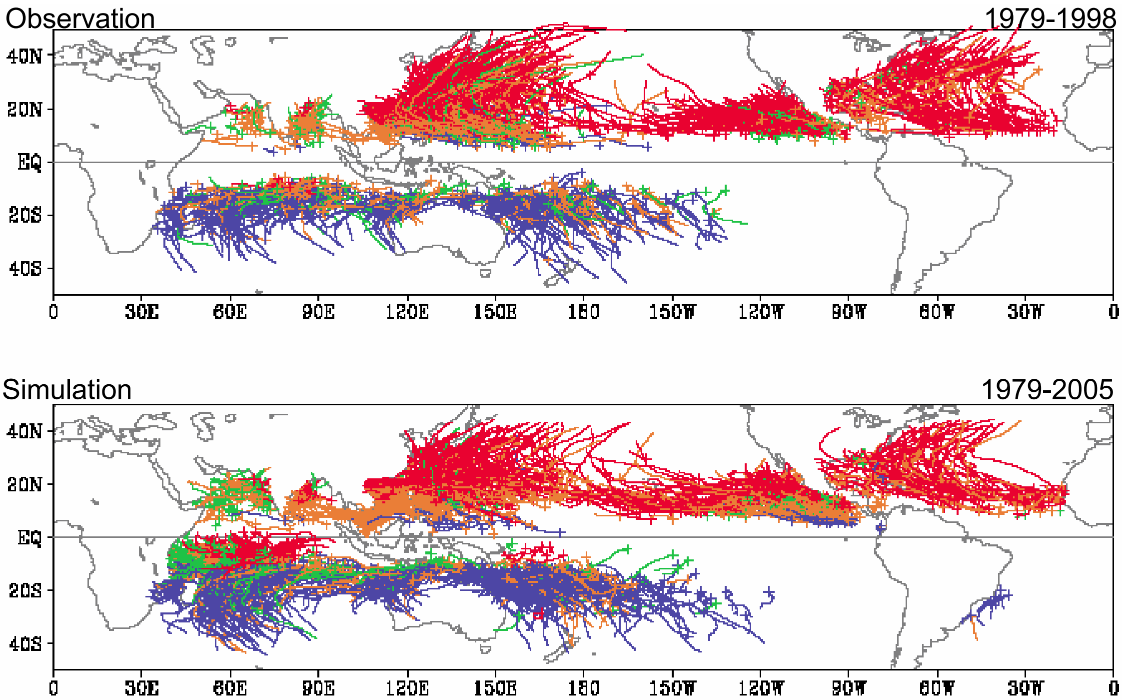


Fig. 3.2.15 Observed tracks of tropical cyclones around the world and simulated tracks in a model

The plus (+) signs indicate points where individual tropical cyclones are formed. The blue lines indicate cyclones formed in January to March, the green ones from April to June, the red ones from July to September, and the orange ones from October to December.

Source: Meteorological Research Institute et al., 2007

Tropical cyclone projection studies using this model indicate a trend that while the total number of tropical cyclones will decrease as global warming advances in the future, the number of extremely strong tropical cyclones, with maximum wind speed of 44 m/s or more, will increase globally (Fig. 3.2.16) and precipitation associated with tropical cyclones will be heavier. It is also projected that such trend will become more prominent when the degree of warming is greater (greater increase in sea surface temperatures).

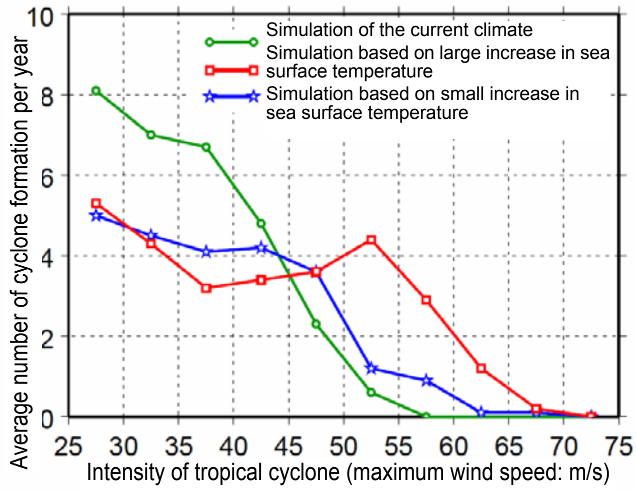


Fig. 3.2.16 Frequency distribution of the average number of tropical cyclones per year based on their intensities in global warming experiments

This graph shows the results of simulations based on observed sea surface temperature, projected sea surface temperature with small progress in warming (small increase in sea surface temperature), and with greater progress in warming (large increase in sea surface temperature).

Source: Meteorological Research Institute et al., 2007

(5) Projection of sea level

The global average sea level is expected to rise as the concentration of CO_2 increases. With regards to the sea level around Japan, however, uncertainties due to significant decadal variations must also be considered.

The global average sea level is projected to rise as the CO_2 concentration increases. According to the projection under six scenarios (B1, B2, A1B, A1T, A2, and A1FI) that use multiple models, the sea level rise at the end of the 21st century ranges from 0.18 m (B1 scenario) to 0.59 m (A1FI scenario) in comparison with the end of the 20th century (Fig. 3.2.17). Thermal expansion of seawater is the most influential factor in sea level rise; thermal expansion is responsible for 70–75% of the best estimates of individual scenarios. Other influences include deglaciation of the ice of land origin (glaciers, ice caps, and ice sheets such as those on Greenland and Antarctica). In addition, there is an undeniable possibility that a drastic sea level rise will occur due to a partial loss of the ice sheet in Greenland and Antarctica some centuries into the future. However, the timing and intensity of this cannot be estimated due to insufficient understanding of the process.

The amount of sea level rise varies in different oceans due to variations in seawater density and oceanic circulation. The sea level rise around Japan is expected to be +0.05–+0.10 m higher than the global average (Fig. 3.2.18). Variability in the sea level around Japan's coast area has been prominent in near 20-year cycle over the past 100 years (Fig. 3.1.11). However, the projection shown here does not take this near 20-year cycle into consideration. Thus, this periodic variation must be included as an uncertainty in a projection of the sea level rise around Japan.

(6) Greenhouse gas stabilization scenario and global temperature increase

All climate change projections discussed so far are based on the IPCC SRES scenario which does not anticipate aggressive measures against climate change (such as implementation of the United Nations Framework Convention on Climate Change and reduction goals of Kyoto Protocol). That is, the climate change projections discussed above "must be or can be avoided" future climate change and aim to gain better perspectives on it.

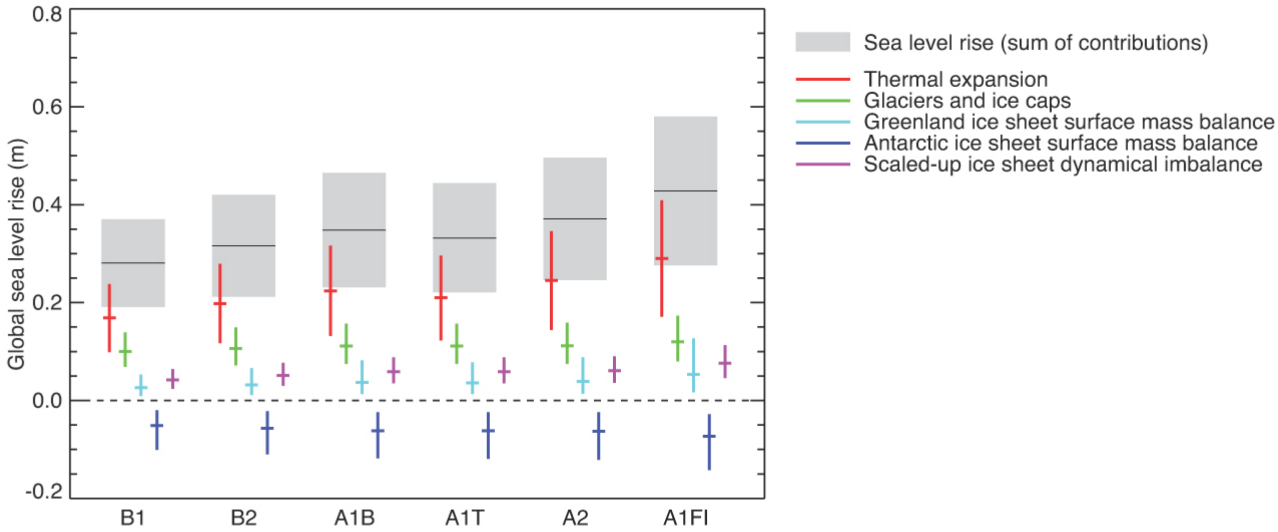


Fig. 3.2.17 Projected global average sea level rise and its components in 2090 to 2099 (relative to 1980–1999) for the six SRES marker scenarios. The uncertainties denote 5 to 95% ranges, based on the spread of model results, and not including carbon cycle uncertainties. The contributions are derived by scaling AOGCM results and estimating land ice changes from temperature changes. Individual contributions are added to give the total sea level rise, which does not include the contribution shown for ice sheet dynamical imbalance, for which the current level of understanding prevents a best estimate from being given.
Source: IPCC, 2007

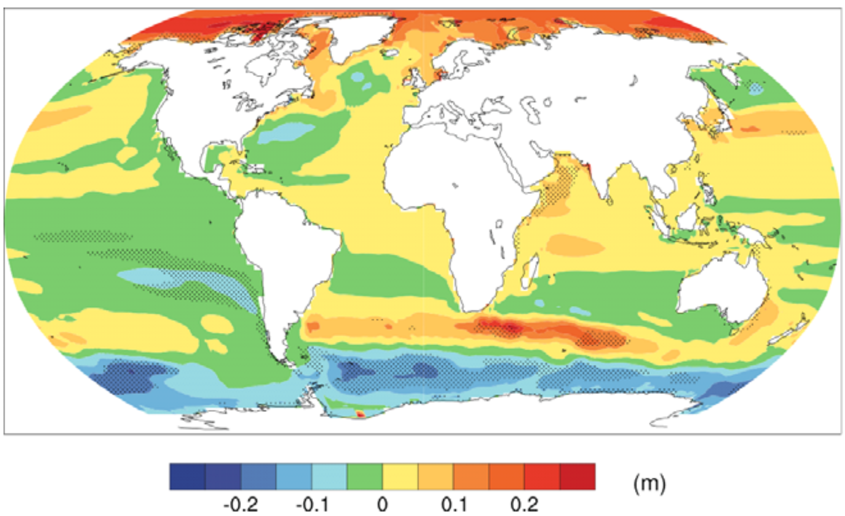


Fig. 3.2.18 Local sea level change (m) due to ocean density and circulation change relative to the global average (i.e., positive values indicate greater local sea level change than global) during the 21st century, calculated as the difference between averages for 2080 to 2099 and 1980 to 1999, as an ensemble mean over 16 AOGCMs forced with the SRES A1B scenario. Stippling denotes regions where the magnitude of the multi-model ensemble mean divided by the multi-model standard deviation exceeds 1.0.
Source: IPCC, 2007

In today's international society, there are ongoing discussions that aim to minimize warming through mitigation measures. IPCC AR4 organizes stabilization scenarios[27] released as research results up to the time of its publication and categorizes them in six groups from I to VI. In relation to this categorization, the following scientific information has been obtained regarding the relationship between stabilization levels of GHGs and the amount of increase in global average temperature.

The graph on the left in Figure 3.2.19 shows the time series of global CO_2 emissions for each scenario category. The graph on the right shows the relationship between the stabilization level of GHGs and the degree of global average temperature increase. One point to note is that the "equilibrium global average temperature increase above pre-industrial (°C)" on the Y-axis in the graph on the right indicates values in "equilibrium." That is, even after the concentration is stabilized, the temperature will continue to increase for a few centuries until all climate systems including the ocean reach equilibrium, and the graph is showing values for the time the increase finally stabilizes. Therefore, for example, the warming in 2100 will be smaller than this value (about 60–80%).

In addition, there are uncertainties in the scientific relationship between the stabilizing concentration of GHGs and warming. The best estimate of warming in equilibrium when the CO_2 concentration doubles (called "climate sensitivity") is 3°C, and the likely range is expected to be very likely within 2–4.5°C. In the graph on the right in Figure 3.2.19, the dark blue line corresponds to a case in which the climate sensitivity is 3°C, the red line 4.5°C, and the blue line 2°C. It is important to recognize such scientific uncertainties when referring to the relationship between stabilizing concentration of GHGs and the amount of equilibrium warming when examining goals of global warming measures.

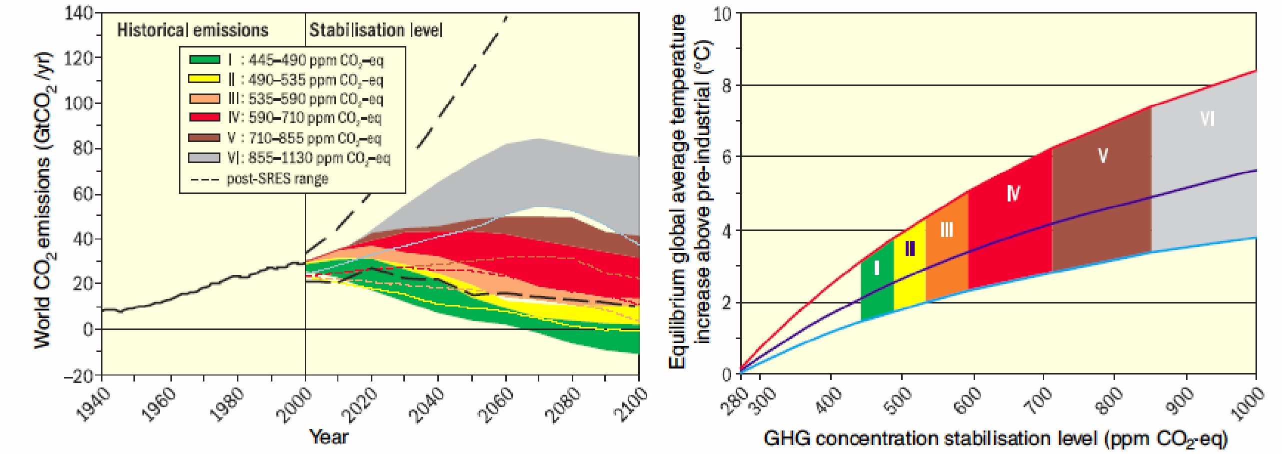


Fig. 3.2.19 Global CO_2 emissions for 1940 to 2000 and emissions ranges for categories of stabilisation scenarios from 2000 to 2100 (left-hand panel); and the corresponding relationship between the stabilisation target and the likely equilibrium global average temperature increase above pre-industrial (right-hand panel). Approaching equilibrium can take several centuries, especially for scenarios with higher levels of stabilisation. Coloured shadings show stabilisation scenarios grouped according to different targets (stabilisation category I to VI). The right-hand panel shows ranges of global average temperature change above pre-industrial, using (i) 'best estimate' climate sensitivity of 3°C (black line in middle of shaded area), (ii) upper bound of likely range of climate sensitivity of 4.5°C (red line at top of shaded area) (iii) lower bound of likely range of climate sensitivity of 2°C (blue line at bottom of shaded area). Black dashed lines in the left panel give the emissions range of recent baseline scenarios published since the SRES (2000). Emissions ranges of the stabilisation scenarios comprise CO_2-only and multigas scenarios and correspond to the 10th to 90th percentile of the full scenario distribution. Note: CO_2 emissions in most models do not include emissions from decay of above ground biomass that remains after logging and deforestation, and from peat fires and drained peat soils.
Source: IPCC, 2007

[27] Unlike the IPCC SRES scenario, this is a socioeconomic emission scenario that aims to stabilize the atmospheric concentration of greenhouse gases at a certain level through aggressive climate change measures.

[Column 7] Climate change projection models and the Earth Simulator

The world's most advanced vector parallel processor[28] at that time, called the Earth Simulator (ES), with the theoretical peak performance of 40 TFLOPS[29] was developed in Japan as a supercomputer to be used for earth sciences and has been in operation since 2002.

At the same time, MEXT launched a five-year research initiative called the *Kyosei Project* (Research Revolution 2002 (RR2002)) including climate change projection studies using the ES in 2002. The main achievements of these studies made advanced and leading contributions to in IPCC AR4.

The group of the Center for Climate System Research of The University of Tokyo, the National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology Center[30] **(CCSR/NIES/JAMSTEC)** developed a coupled atmosphere-ocean model with advanced physical processes and the highest resolution among coupled models in the world. They ran numerical simulations to specify causes of warming and their result served as a leading grounds for an important conclusion of IPCC AR4' "Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations." The group also projected by its global model the future melting of Arctic sea ice, present simulation and future projection of the Kuroshio Current, and future changes in extreme events such as the increase in the number of summer days and the frequency of heavy precipitations over and around Japan.

The group of **Central Research Institute of Electric Power Industry (CRIEPI) and other** ran long-term projections covering over 100 years and beyond using a model of National Center for Atmospheric Research (NCAR) in the U.S. Their results include new findings related to long-term stabilization produced under a hypothetical scenario (Overshoot Scenario) that starts from a higher emission and then shifts to a lower emission scenario through a transition process, and projection that the North Atlantic meridional overturning circulation will be weakened towards the end of the 21st century. These were reflected in IPCC AR4.

The group of **JAMSTEC's Frontier Research Center for Global Change**[31] **and others** ran a simulation that integrated the feedback of CO_2 into the atmosphere of their climate change projection model through the carbon cycle on the land and in the marine biosphere. When the carbon cycle was introduced under a higher emissions scenario, the group reached a quantitative finding as shown in IPCC AR4 that the atmospheric concentration of CO_2 would increase by 10–25% by the end of the 21st century.

Group of the **Meteorological Research Institute of JMA and others** newly developed global atmospheric model with super high resolution of over 20 km and reasonably well reproduced the formation, development, and dissipation of tropical cyclones. It also projected the behavior of tropical cyclones under the future climate. The result provided an important basis for conclusion of IPCC AR4, "it is likely that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation." Other results include detailed regional projections over and around Japan.

The Earth Simulator (ES2)
Courtesy: JAMSTEC

Kyosei Project was dissolved but followed up with a constructive context to form to a new initiative of the Innovative Program of Climate Change Projection for the 21st Century (*KAKUSHIN*), under which substantial and projection experiments are now being conducted using the Earth Simulator. The Earth Simulator (ES) was updated to a new version (ES2) in 2009, with its increased theoretical peak performance became of 131 TFLOPS.

28 A computer consisting of a connection of multiple computers with processors that continuously perform computation (four arithmetical operations) on multiple data allocated on the memory when given an order.
29 The unit indicating the processing speeds of the computer. 40 TFLOPS means that the computer is capable of 40 trillion computations per second.
30 Japan Marine Science and Technology Center (JAMSTEC) until March 2004
31 JAMSTEC's Frontier Research System for Global Change until March 2004. Dissolved in April 2009.

4. Impacts of, and adaptation to, climate change

4.1 Impacts of climate change on different sectors – What kind of impacts will occur in different sectors?

There are two important reasons to determine the impacts of climate change. The first is to obtain evidence for examining the level of necessary measures by knowing the degree of threat that climate change will bring. Climate change measures must aim to limit climate change to a level that would not be hazardous to humans. The projection of climate change provides essential information to make this judgment. The second reason is that knowing future impacts enables us to take disaster prevention, agricultural and other measures to prepare for negative impacts. Such measures are called adaptation. A combination of adaptation measures and mitigation measures, the measures to reduce GHG emissions, is necessary to address climate change. Along-term commitment to these two measures is essential.

Climate change is the most fundamental change to the Earth's environmental systems including its temperature and precipitation. Therefore, its effect is likely to be seen in an extremely wide range of sectors, such as hydrologic circulation and water resources, water hazards and coastlines, terrestrial and marine ecosystems, agriculture, forestry, fisheries, human health, and industry. Expected impacts can be both positive and negative. An example of a positive impact is the increased photosynthetic activity due to increased atmospheric CO_2 concentration. This will result in higher grain yields (fertilization effect). Nonetheless, research up to this point has projected more negative effect than positive ones.

Projecting impacts requires knowledge of future climate (average temperature, precipitation, sea-level rise, amount of solar radiation etc.), based on outputs of climate change projection models. Projected impacts will vary depending on climate change models, and then estimating the impacts that could occur under those conditions. Under such circumstances, projected impacts will vary among climate change projection models. Climate impact projection is thus associated with uncertainties. There is growing awareness about considering uncertainties when projecting effects.

IPCC AR4 points out that the impacts of climate change have already begun to appear around the world. Specific examples include shrinking sea ice cover within the Arctic region, where the temperature increase is most pronounced, and organisms that have quickly responded to the temperature change and begun to migrate toward the North Pole (in the northern hemisphere) or higher elevation in mountainous regions.

In the late 20th and early 21st centuries, intensified heat waves, typhoons, flooding, and droughts have had a great impact on people's lives and agriculture. Although it is impossible to establish an association between individual natural disasters and climate change, both the frequency of, and damage caused by, disasters have been increasing.

According to a projection made at IPCC AR4, the following serious impacts will become more widespread in the 21st century. There will be serious impacts such as reduced fresh water resources, species extinctions, storm surge flooding, and submergence due to sea-level rise, food crises, and health effects. On a global scale, when the mean temperature increases 1–3°C from the 1980–1999 level, some sectors may benefit such as agriculture in colder regions. However, economically negative effects are expected to dominate in all parts of the world if the temperature increases 2–3°C or more. The following four regions are identified as being especially vulnerable to climate change: the Arctic region, where a high degree of warming is expected; Africa, where the adaptive capacity is low and severe impacts are expected (especially in Sub-Saharan Africa); small island nations with high vulnerability; and mega-deltas[32] in Asia and Africa with a high risk of population growth, sea-level rise, storm surge, and river flooding.

What impacts will Japan experience? The high-temperature damage to rice in Kyushu, and an unprecedented increase in heavy rains and related flooding and landslides are indications of the impacts of climate change that are already occurring in Japan. Further, a series of reports that were recently released expect that Japan will experience substantial impacts at least throughout the 21st century. Section 4.1 discusses the observed and projected impacts of climate change in different sectors in Japan.

(1) Change in annual average temperature and sector-specific impacts

In Japan, the impacts of, and damage caused by climate change are expected to occur in a wide variety of sectors in the future.

IPCC AR4 summarizes possible impacts in different sectors based on various degree of global average temperature increase from 1980-1999 levels, as shown in Figure 4.1.1. Specific projections in individual impacts include widespread coral bleaching and habitat change among organisms given with a 1°C warming. With a 1–2°C warming, agricultural yields will increase in high latitude regions, while the productivity will decrease in low latitude regions, especially in dry tropical regions. There will be increasing starvation risks and mortality due to heat waves. Serious impacts are likely to occur in vulnerable regions, especially in developing countries, even when the warming remains below 2–3°C.

Figure 4.1.2 is a chart summarizing the consequence of average temperature increase for different sectors in Japan, and the estimated cost of related damages, based on the projections of the Project Team for Comprehensive Projection of Climate Change Impacts (GERF S-4) (2009). Average temperature is used as an indicator for the extent of climate change. In Japan various influences and types of damage are expected with a warming of only 1.7°C from the 1981-2000 level; for example, around 30 % of pine trees that used to be located in not-at-risk areas will become areas at risk, and the mortality risk from heat stress will increase over 2-fold. Also, when the average warming becomes 3.2°C in Japan, the estimated total cost of damage from flooding, landslide, loss of suitable habitats for beech forest distribution, loss of sandy beaches, damage from storm surges in western Japan, and mortality risk from heat stress would reach approximately 17 trillion yen per year (in present value, no discounting applied). On the other hand, if the warming is kept to around 2°C up to the end of the 21st century, through a drastic reduction of GHG emissions, the impacts and damages are expected to reduce substantially. Nonetheless, the estimated total cost of damage from the same impacts as above (flooding, landslide, loss of suitable habitats for beech forest distribution, loss of sandy beaches, damage from storm surges in western Japan, and mortality risk due to thermal stress) is approximately 11 trillion yen (in present value, no discounting applied), indicating that certain damages are unavoidable regardless of mitigation efforts.

Example of the impacts of climate change under future climate projections in Japan, and preliminary estimations of damages associated with the impacts are discussed below for individual sectors. The example, those include without a conclusive causal relationship with climate change at this point. However, the following discussion includes those examples that are considered highly likely to be related to climate change and impacts that are expected to increase when climate change becomes more apparent.

When projecting the impacts, a specific GHG emission scenario is assumed and the results climate

[32] Flat and low-lying depositional land form created in an area where a river meets the ocean. Vast deltas formed at the mouths of large rivers such as the Ganges and the Mekong are called mega-deltas.

change scenario derived by a climate change model is used. The estimates of impacts described in this report mainly used climate change projections based on the regional climate model RCM20[33] (emissions scenario SRES A2) and global climate model MIROC[34] (emissions scenario SRES A1B). Projections based on MIROC (emissions scenario SRES B2) are used to estimate the damage costs. Estimates of impacts and damage costs depend on emissions scenarios and climate change projection models. Thus, it is necessary to be aware that using different scenarios and models will produce different estimates of impacts and damage costs.

IPCC AR4, and the outcome of global-wide research on impacts have become the basis for specifically determining "a level that would prevent dangerous anthropogenic interference with the climate system". This is done by combining the climate change projections discussed in Section 3.2 and analysis of stabilization scenarios. With regards to this level in terms of global average temperature, the G8 L'Aquila Summit in July 2009 and Major Economies Forum stated, "We recognise the broad scientific view that the increase in global average temperature above pre-industrial levels ought not to exceed 2°C". It is also important to recognize that the negative impacts of climate change will occur in some regions and sectors even when the increase in global average temperature is below 1°C, as shown in Figures 4.1.1 and 4.1.2.

Also, global temperature has already increased by 0.5°C above pre-industrial levels to the 1980–1999 and 1981–2000 levels used as reference points in Figures 4.1.1 and 4.1.2. Thus "2°C from the pre-industrial level" actually means 1.5°C from the 1980–1999 or 1981–2000 levels.

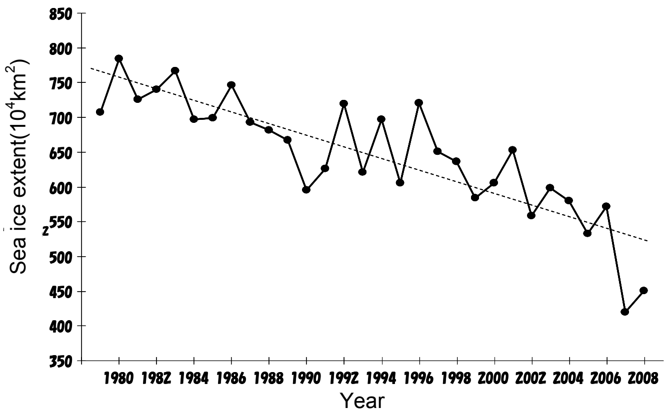
33 Regional climate model of 20 km horizontal resolution developed by the Meteorological Research Institute of the Japan Meteorological Agency. Climate scenario used SRES A2 as an emissions scenario.

34 High-resolution coupled atmosphere-ocean climate model with horizontal resolution of 1.125º (about 100 km) developed by the joint research team of Tokyo University Center for Climate System Research, the National Institute for Environmental Studies, and the JAMSTEC Frontier Research Center for Global Change. The climate scenario used SRES A1B as an emissions scenario.

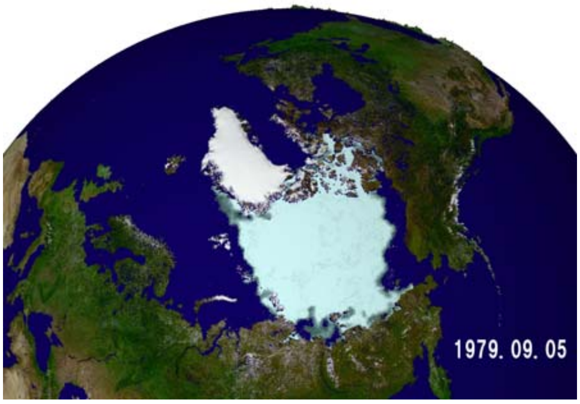
[Column 8] Large and abrupt changes in earth system

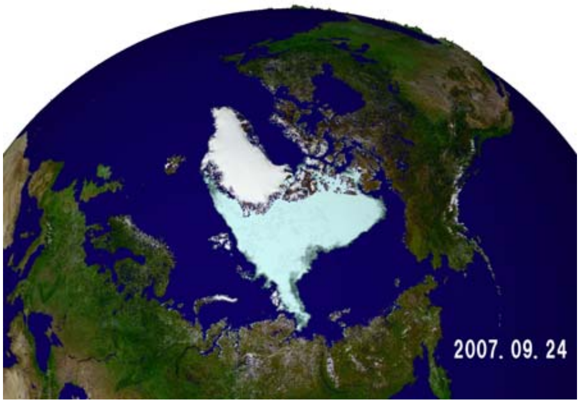
When considering the impacts of climate change, we must pay special attention not only to effects of changes in temperature and precipitation which gradually progress, but also the impacts of large and abrupt changes in the Earth system.

For example, global warming will be accelerated immediately as a result of the reduced sea ice area in the Arctic region increasing the amount of radiation absorbed by the sea surface. The IPCC AR4 are suggestions that almost all the late summer sea ice in the Arctic region will vanish by the latter half of the 21st century. The figure to the right shows observed changes in the annual minimum extent of Arctic sea ice. This has been on the decline, and recorded its smallest extent in September 2007 (Figure below).



Annual minimum extent of Arctic sea ice from 1979 to 2008
(The dotted line shows a linear trend.)
Source: Adapted from JMA, 2006





Comparison of Arctic sea ice covers acquired in Sept. 1979 (Left) and Sept. 2007 (Right; smallest on record by satellites)

For the sea ice extent in 1979, data observed by the NASA SMMR was used; for the sea ice extent in 2007, data observed by the Japan Aerospace Exploration Agency (JAXA) AMSR-E was used.
Source: Japan Aerospace Exploration Agency

According to the IPCC AR4, if the global average temperature continues to stay at 1–4°C higher than that of 1990 to 2000, the Greenland and West Antarctica[35] ice sheets will melt away in some hundreds or thousands of years, raising sea levels by 4 to 6 m or more. If the Greenland ice sheet completely melts away, it is projected to raise sea levels by approx. 5 m, and if the West Antarctica ice sheet disappears it may raise sea levels by up to 7 m.

[35] At the 0 to 180 degree longitude line, the east hemisphere side of Antarctica is called "East Antarctica" and the west hemisphere side is called "West Antarctica". Antarctic Peninsula extending toward South America, Ross Sea and Weddell Sea are in this area.

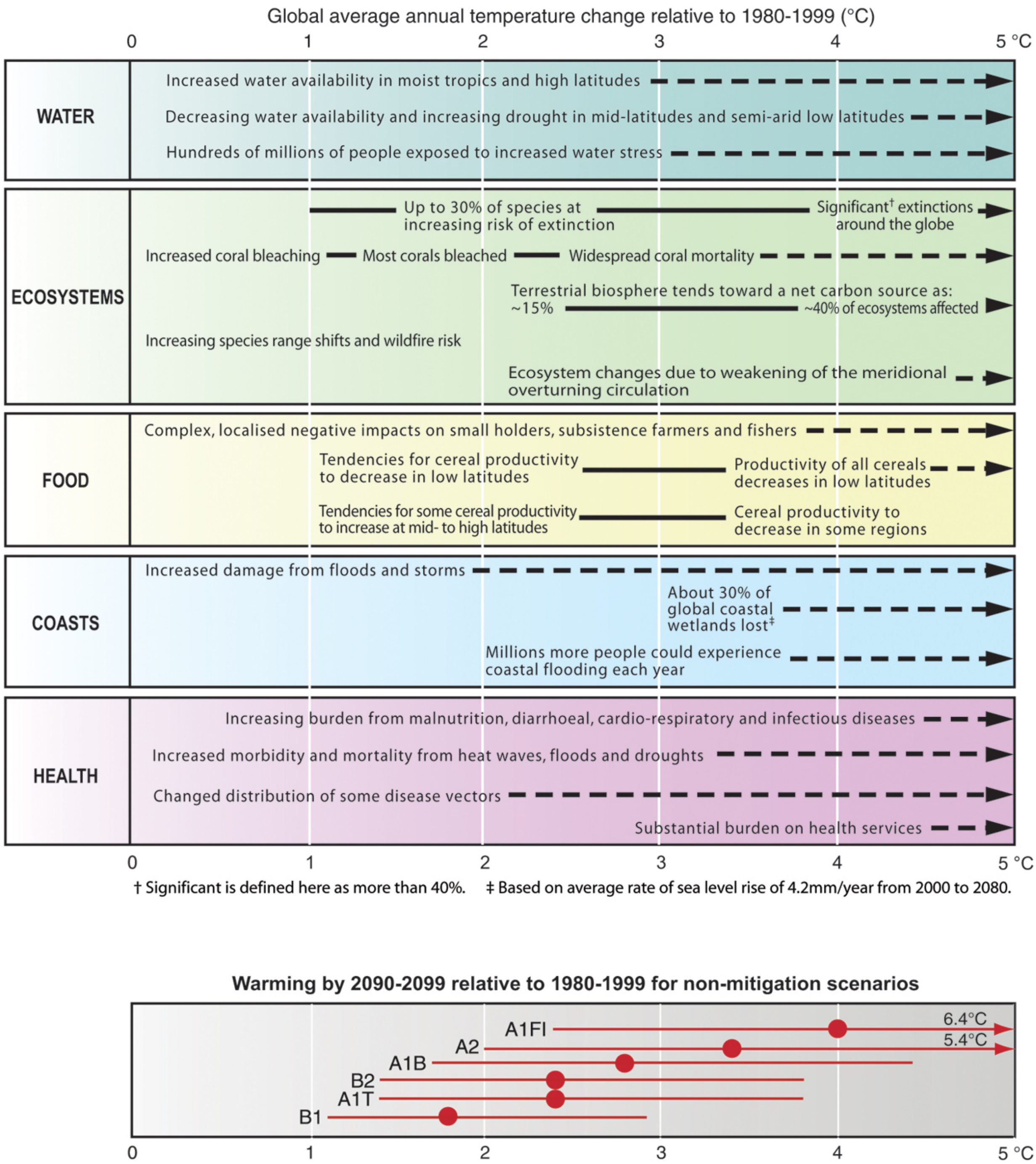
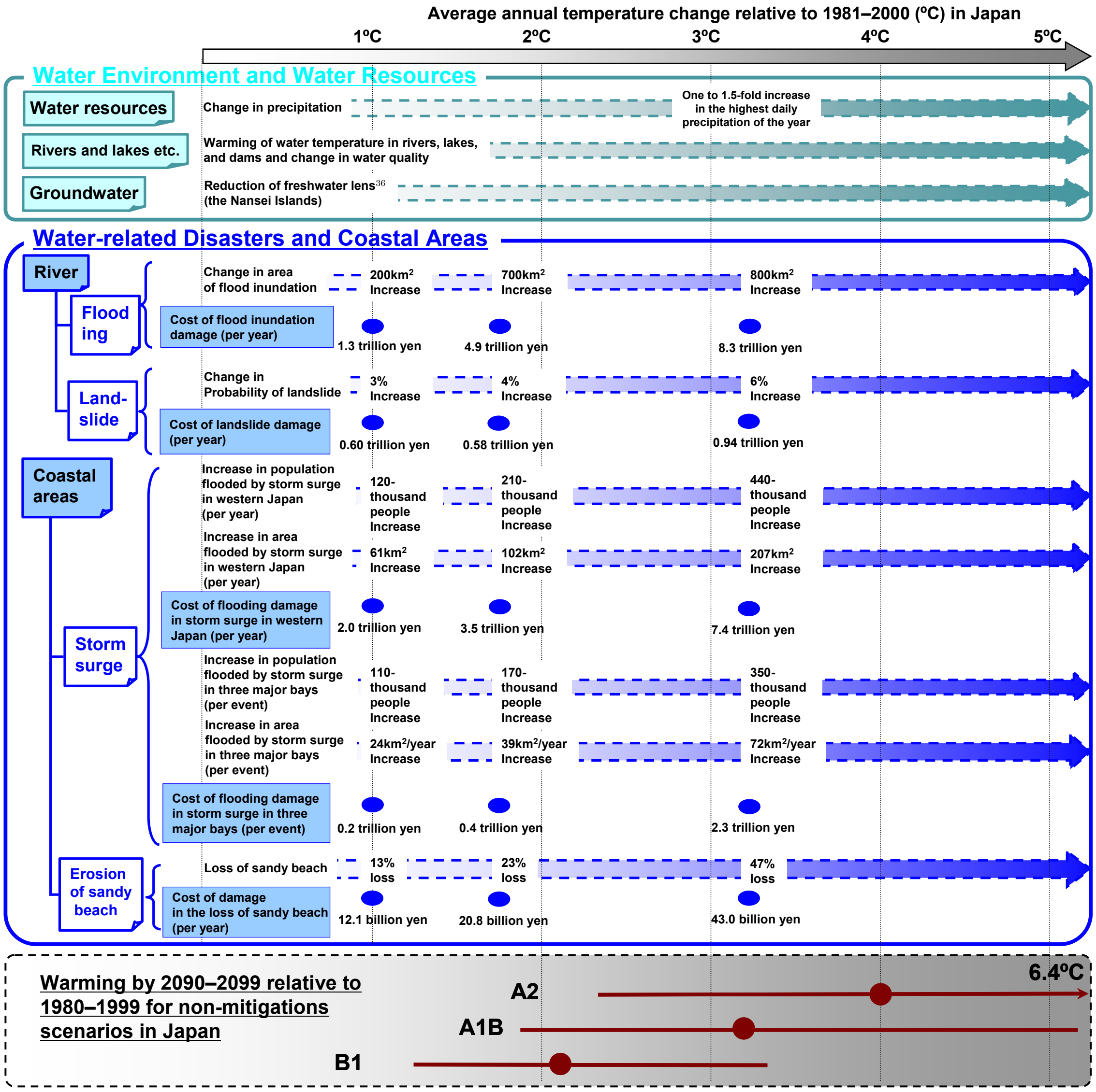


Fig. 4.1.1 Examples of impacts associated with projected global average surface warming

Upper panel: Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric CO2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. The black lines link impacts; broken-line arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left-hand side of text indicates the approximate level of warming that is associated with the onset of a given impact. Quantitative entries for water scarcity and flooding represent the additional impacts of climate change relative to the conditions projected across the range of SRES scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. Confidence levels for all statements are high. Lower panel: Dots and bars indicate the best estimate and likely ranges of warming assessed for the six SRES marker scenarios for 2090-2099 relative to 1980-1999.

Source: IPCC, 2007

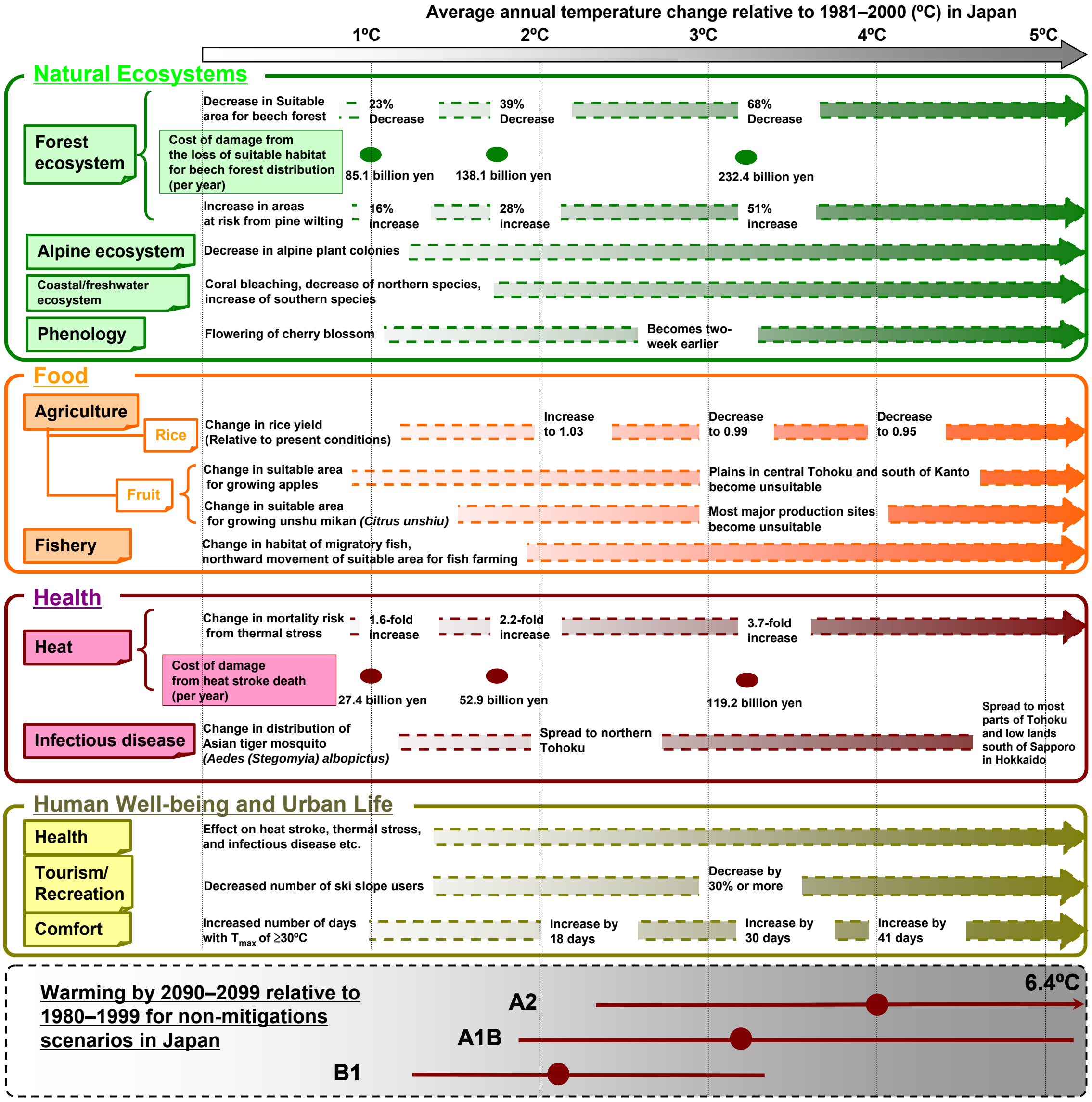


1) This chart shows warming projection based on projections in Figure 3.2.5, with likely range of projection between -40 and +60% of average projected values as in Figure 4.1.1. The same applies to Figure 4.1.2 (2).
2) The projected quantitative impacts are based on the 1981–2000 level as reference. The same applies to Figure 4.1.2 (2).
3) The analytical result under the SRES B2 scenario is used to calculate impacts and cost of damage from flooding, landslides, storm surge inundation, and loss of sandy beaches. Precipitation and sea-level rise that have substantial influences on the onset of each effect are based on the following projections (amount of change based on the 1981–2000 level: change in annual average precipitation is indicated in % and sea-level rise in cm). (Project team for Comprehensive Projection of Climate Change Impacts (GERF S-4), 2009)
   - O 1.0°C increase in average temperature: 1% increase in annual average precipitation and 7 cm increase in sea level
   - O 1.7°C increase in average temperature: 7% increase in annual average precipitation and 12 cm increase in sea level
   - O 3.2°C increase in average temperature: 13% increase in annual average precipitation and 24 cm increase in sea level
4) Comments on evaluations of impacts in each category
   Change in precipitation: Projection for 2081–2100 (using RCM20) is presumed from a degree of warming during the same period. (MLIT, 2008)
   Warming of water temperature in rivers, lakes, and dams and changes in water quality: Estimated based on the past changes. (Ozaki et al., 1999), (Fukushima et al., 1998), and (Kusaba et al., 2007)
   Reduction of freshwater lens (the Nansei Islands): Qualitative estimate (Jinno et al., 2006)

Fig. 4.1.2(1) Examples of impacts associated with projected average surface warming in Japan (1)

The arrows indicate that the impact continues along with warming. The descriptions are located so that the beginning of the sentence (left side) aligns with an approximate level of warming where the impact begins to appear. The simulation calculation of damage costs indicates an example of simulation calculation under a certain level of warming (the same applies to Figure 4.1.2(2)).
Source: Adapted from Project team for Comprehensive Projection of Climate Change Impacts (GERF S-4), 2009

[36] A phenomenon in which the groundwater (freshwater) of an island floats above the seawater (salt water) in the form of a lens due to the differences in specific gravity of seawater and fresh water underneath permeable soil.



1) Analytical result under SRES B2 scenario is used to identify changes of suitable habitats for beech forest distribution and mortality risk due to thermal stress and calculation of costs of these damages. (Project team for Comprehensive Projection of Climate Change Impacts (GERF S-4), 2009)

2) Comments on evaluations of impacts in each category

Suitable habitats for beech forest distribution: Suitable habitat for beech forest distribution is an area in which probability distribution of beech forest is 0.5 or higher. (Project team for Comprehensive Projection of Climate Change Impacts (GERF S-4), 2009)

Pine wilting: The ratio at which pine distribution areas that used to be outside areas at risk turn into areas at risk is estimated. (Project team for Comprehensive Projection of Climate Change Impacts (GERF S-4), 2009)

Loss of alpine plant colonies: (The Committee on Climate Change Impacts and Adaptation Research, 2008), (Masuzawa, 2005), and (Naganuma et al., 2006)

Coral bleaching, decrease of northern species, and increase of southern species: Reviews of multiple studies (Hughes et al., 2003), (Harley et al., 2006), and (Nakano et al., 1996)

Flowering of cherry blossom: Effect of increased CO_2 concentration is not considered. Projection for 2082–2100 (using RCM20) is presumed from the warming in the same period. The average temperature increase in the spring time (February to April) at which the flowering of cherry blossom occurs two weeks earlier than normal year is approximately 3.3°C. (Shimizu et al., 2007)

Rice yield: Effect of increased CO_2 concentration is taken into account. Regionally, rice yields in Hokkaido and Tohoku will increase along with warming, but the yield in western Japan begins to decrease when the warming is about 3°C or higher. (Project team for Comprehensive Projection of Climate Change Impacts (GERF S-4), 2008)

Suitable area for growing fruits: Effect of increased CO_2 concentration is not considered. New areas become suitable for growing fruits. (Sugiura et al., 2004)

Change in habitat of migratory fish, northward movement of suitable areas for fish farming: (Ito, 2007a), (Ito, 2007b), and (Kuwahara et al., 2006)

Mortality risk from thermal stress: Prefecture-specific optimum temperature[37] is estimated using past data, and excess mortality from high temperature (mortality risk from thermal stress) is projected with an assumption that the optimal temperature will not change in the future. (Project team for Comprehensive Projection of Climate Change Impacts (GERF S-4), 2009)

Asian tiger mosquito (*Aedes (Stegomyia) albopictus*): Projections for 2035 and 2100 (using MIROC) is applied to warming in the same years. (Kobayashi et al., 2008)

Heat stroke, thermal stress, infectious disease etc.: Estimated based on knowledge and information in the health sector (The Committee on Climate Change Impacts and Adaptation Research, 2008)

Ski slope users: Number of users of ski slopes is expected to decrease by 30% or more in most ski slopes besides Hokkaido and high-elevation Chubu regions. (Fukushima et al. 2002)

Number of days with T_{max} of ≥30°C: Based on Figure 3.2.7.

Fig. 4.1.2(2) Examples of impacts associated with projected average surface warming in Japan (2)

[37] In the relationship between temperature and death, the temperature at which the mortality is the lowest on the relationship curve (V-shaped curve) of the temperature and total mortality.

(2) Water Environment and Water Resources

With a wider fluctuation of annual precipitation, heavy rain will be more frequent, and drought risk will increase. It is expected that such risks will increase in the future, and lake water quality will decline due to increasing water temperatures and an inflow of turbid water.

The impact of climate change on water resources is strongly related to changes in precipitation. More frequent low rainfall raises the risk of droughts, and more frequent heavy rainfall raises the risk of flooding. Changes in precipitation and the water temperature of rivers, lakes and groundwater, shift the flow of rivers, increases evaporation, decreases snowfall, modify the snow period, change lake water levels and degrade water quality. This affects the water supply and ecosystems. In addition, it is thought that increasing sea level cause saline groundwater and saline water run-up causes water intake problems.

As evidence of observed changes in the current impact obtained from climate, the IPCC AR4 listed increased flow of glacier and snow-fed rivers, an earlier peak flow in spring and the impact of higher water temperatures on the conditions of rivers and lakes. Projections for the middle of this century, suggest t that the annual average flow of rivers, and the usable amount of water, will increase 10–40% in some tropical humid areas, but will decrease 10–30% in some arid and tropical areas.

As shown in Figure 3.1.7, the annual precipitation in Japan tends to vary widely. This means that the risks of droughts and floods will rise simultaneously. In the future, these risks are expected to increase. The flow of rivers is affected by the amount of snow-melt water discharge and rainfall rate[38]. Figure 4.1.3 compares the current amount of snow-melt water and rainfall with a projection of the situation 100 years from now (MLIT, 2007). From March to June, the amount of snow-melt water and rainfall is projected to decline in many areas. That is, the river flow will decrease in the season when agricultural water is required, e.g., the planting and survival period, and will have a significant impact on water usage after the beginning of spring.

There will be deterioration in river water quality due to heavy rain and droughts, an inflow of turbid water caused by heavy rain, increased evaporation caused by rising water temperatures and discontinuity of overall circulation in lakes and reservoirs[39]. As a result, the water quality of lakes and reservoirs will decline, and subsequently the ecosystem and water supplied for human use will be affected.

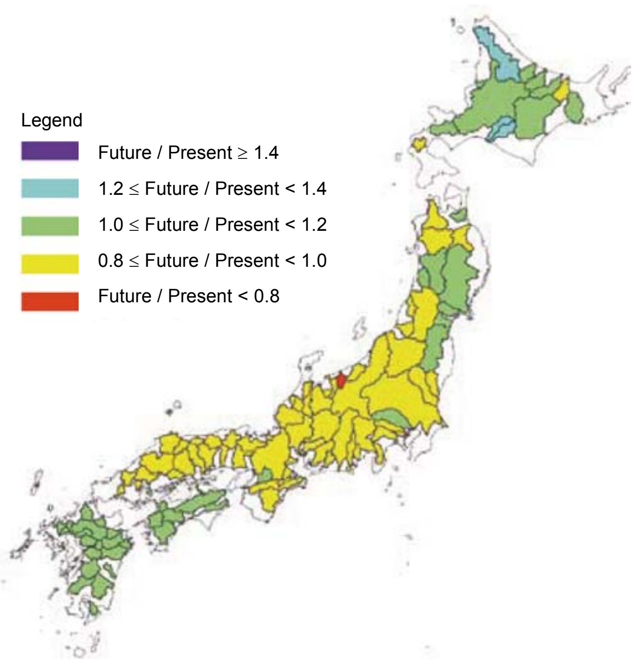


Fig. 4.1.3 For class A river systems[40], comparison of the water amount snow-melt water and rainfall between the current state (1979 to 1998) and a future one (2080 to 2099) (in spring, March to June)

Source: MLIT, 2007

[38] Total water amount including snow-melt water and rainfall

[39] Surface water and deep water are mixed in reservoirs and lakes.

[40] River systems that the Minister of Land, Infrastructure, Transport and Tourism designated as important river systems especially from the perspective of land preservation and the national economy. 109 river systems are designated nationwide.

(3) Water-related Disasters and Coastal Areas

Damage, such as that due to floods caused by rising sea levels and record rainfall, is increasing. In the future, the expansion of flooded areas, and loss of beaches, will be caused by rising sea levels. Damage from more frequent floods due to stronger typhoons will increase.

Changes in water-related disasters caused by climate change are roughly classified into two groups: One is river floods and sediment disasters caused by increased frequency of heavy rainfall events, and the other is the growing number of flood disasters such as high-wave disasters caused by storm surge and increased typhoon intensity.

The IPCC AR4 notes that heavy rain and extremely storm surge are likely to occur more frequently. It also projects that some millions of people will suffer from floods caused by rising sea levels every year, by 2080. People living in low-altitude areas in Asia and the delta areas of Africa will suffer the worst damage.

In Japan, river and sediment disasters, flood damage caused by heavy rainfall, and rising sea level-related damages are projected to increase. Figure 4.1.4 shows the estimated flood areas caused by storm surge in western Japan in 2100, due to changing sea levels and typhoon strength. The estimates use the climate change projection model MIROC (Emissions scenario: SRES A1B) (Project Team for Comprehensive Projection of Climate Change Impacts (GERF S-4), 2008). Areas which are assumed to have risks of storm surge floods are coastal regions of closed sea areas, in which relatively low-level protective measures have been taken. Figure 4.1.5 shows storm surge flood depth in three major bays (Tokyo Bay, Ise Bay and Osaka Bay) for 2100, also projected by using MIROC and the emissions scenario SRES A1B. (GERF S-4, 2008). Areas vulnerable storm surge are primarily located in the coastal areas of southern Tokyo, in Nagoya Port and in the coastal areas of south-central Osaka. Those areas are thought to be relatively old landfills and their surrounding areas.

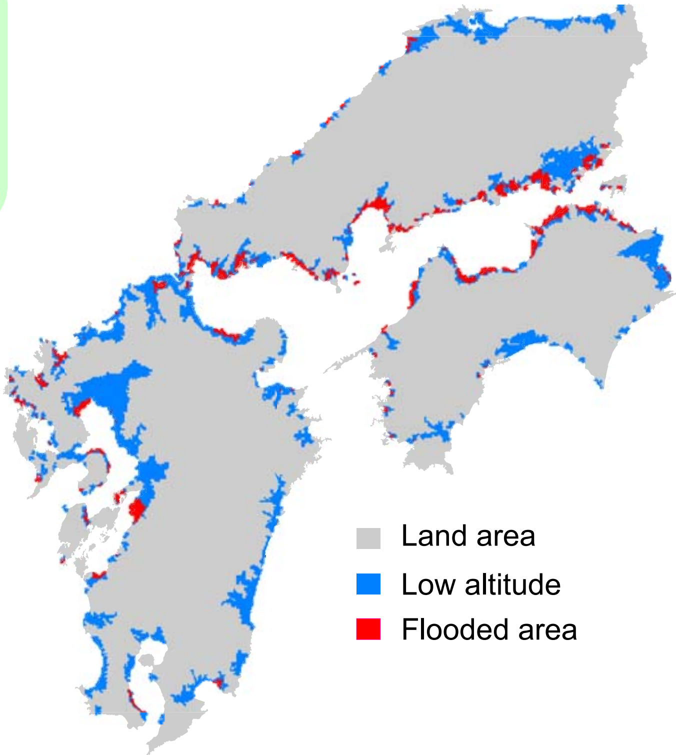


Fig. 4.1.4 Areas of storm-surge flood in western Japan in 2100

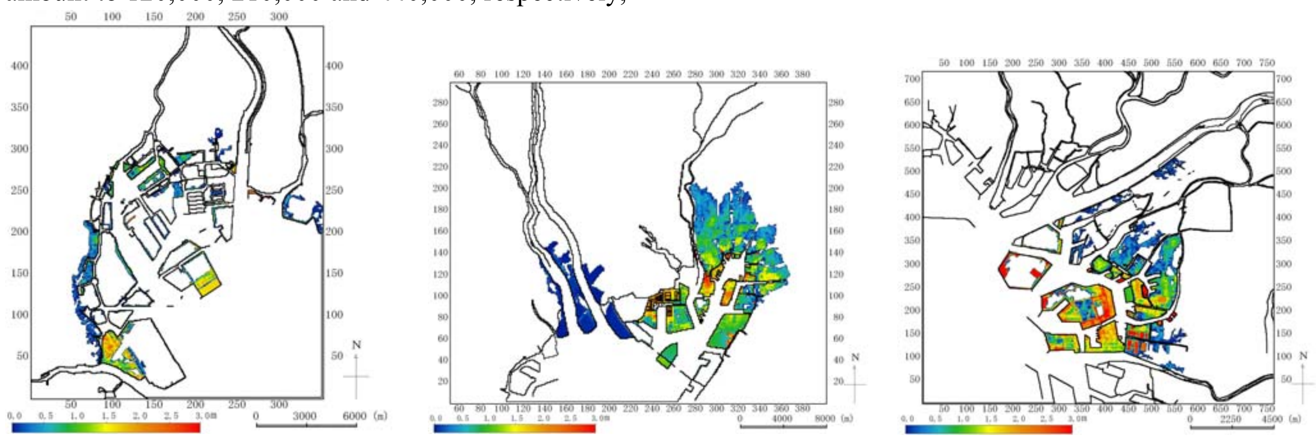
Source: GERF S-4, 2008

With more frequent record heavy rain in the future, the risk of river flooding and overflow is projected to increase. For example, in the Tohoku district, floods have occurred once a century so far, but they will increase in number and occur once every 30 years (MLIT, 2008).

The damage costs of floods and sediment disasters caused by higher rain intensity and more frequent heavy rain have been estimated by setting the daily average precipitation between 1981 and 2000 at 100. When the daily average precipitation is 101, 107 or 113, the flood damage will cost 1.3, 4.9 or 8.3 trillion yen/yr, respectively. The slope failure will cost 0.6, 0.58 or 0.94 trillion yen/yr, respectively (GERF S-4, 2009).

For flood damage (damage per largest-class typhoon) caused by storm surge, when the rise of sea level is 7, 12 or 24 cm, compared to the levels between 1981 and 2000, it is projected that the population which suffers from storm surge floods in three major bays will amount to 110,000, 170,000 and 350,000, respectively. The storm surge flood area will be 24, 39 and 72 km^2/yr, respectively. Accordingly, it is estimated that the damage will cost 0.2, 0.4 and 2.3 trillion yen/yr. In western Japan, when the rise of sea level is about 7, 12, or 24 cm, it is projected that the population which suffers from storm surge flood will amount to 120,000, 210,000 and 440,000, respectively, and the storm surge flood area will be 61, 102 and 207 km^2/yr, respectively. Accordingly, it is estimated that the damage will cost 2.0, 3.5 and 7.4 trillion yen/yr, respectively. (GERF S-4, 2009).

In addition, for rising sea level-caused loss of beach, when the rise of sea levels is about 7, 12, or 24 cm, the beach area that vanishes is projected to be 13, 23 and 47%, respectively. Accordingly, it is estimated that the damage will cost 12.1, 20.8 and 43 billion yen/yr, respectively. (GERF S-4, 2009).



Tokyo Bay　　Ise Bay　　Osaka Bay

Fig. 4.1.5 Depth of flood caused by storm surge in three major bays in 2100

Source: GERF S-4, 2008

(4) Natural Ecosystems

Negative seasonable effects of climate change, such as a decrease in alpine plants and coral bleaching, earlier blossoming and fall foliage, have already occurred. In the future, adverse impacts will include decrease in suitable habitat for beech forests, expansion of dead pines trees and expansion of coral bleaching.

Originally ecosystems were able to adapt to climate change. But if climate changes faster than the dispersal of organisms, the risk of extinction is likely to be increased. If various factors, such as floods, forest fires and change in land use caused by climate change, are combined, the change will exceed their coping ability, and they are not likely to keep up with changes in their habitats. Due to factors such as higher seawater temperatures, and ocean acidification, caused by the increased CO_2 in the atmosphere dissolving in seawater, similar impacts are also likely to occur in marine ecosystems.

The IPCC AR4 listed observed changes likely to be related to recent change in climate, including earlier spring events and migration of plant and animal species towards the poles and high altitudes. If the rise of the global average temperature exceeds the range of 1.5–2.5°C, approximately 20% to 30% of plant and animal species will face higher rates of extinction. If ocean temperatures rise by about 1–3 °C, coral bleaching will spread, and a wider range of corals will die.

In Japan, many events deemed to be impacts of climate change have been reported. Organisms and ecosystems has moved northwards or to high altitudes (decaying of beech forests near their southern extent, decaying of alpine plant communities (Fig. 4.1.6), decrease of cold water fish habitats and butterflies moving northward), activities of organisms have changed (change of cherry blossom time, fall foliage time and bird egg laying time), and coral bleaching has occurred. In addition to those impacts directly caused by temperature increase , for example, some cases of aridification of wetlands caused by change in snowfall is also thought to be related to climate change.

Fig. 4.1.6 Disappearance of a flower field in Goshikigahara, Daisetsuzan, Hokkaido. (Left: 1990; Right: 2007. Both photos were taken in July. In 2007, there was considerable bamboo grass.)
Courtesy: Associate Prof., Gaku Kudo, Hokkaido Univ.

Figure 4.1.7 presents a projection of future beech tree habitat. Climate projections using two climate models, RCM20 (Emissions scenario: SRES A2) and MIROC (Emissions scenario: SRES A1B), show that the current suitable habitat of beech trees (Distribution probability: Over 0.5) is reduced to 65% and 44%, respectively, between 2031 and 2050, and to 31% and 7%, respectively, between 2081 and 2100 (GERF S-4, 2008). With either of these projections, suitable habitat will disappear in western Japan and on the Pacific side of the mainland. Beech trees are therefore likely to go extinct. In such areas, beech trees will be gradually replaced with different trees.

If the temperature increases about 1.0°C relative to 1981-2000, the beech tree habitat will be reduced by 23%. The associated cost will amount to 85.1 billion yen/yr. This means that a temperature rise of about 1.7°C will reduce the suitable habitat by 39%. Damage costs are calculated at 138.1 billion yen/yr. An increase of about 3.2°C will reduce the suitable habitat by 68%. The damage costs are calculated at 232.4 billion yen/yr (GERF S-4, 2009).

Pine trees distributed in areas where currently tree have no risk of dying will be exposed to the risk of dying: if the temperature rises by about 1.0°C relative to 1981-2000, 16% of the pine distribution areas are projected to be exposed to the risk of dying. With an increase of about 1.7°C, this number will increase to 28%, and with an increase of about 3.2°C, it will increase to 51%. (GERF S-4, 2009)

Cherry blossom time is strongly correlated with temperature. Blossom dates at the end of the 21st century (2082 to 2100) will likely be earlier in most areas in eastern and northern Japan. The blossoming period will also change significantly. Estimates indicate that on average, cherry blossoms will appear about two weeks earlier (Shimizu, et al., 2007).

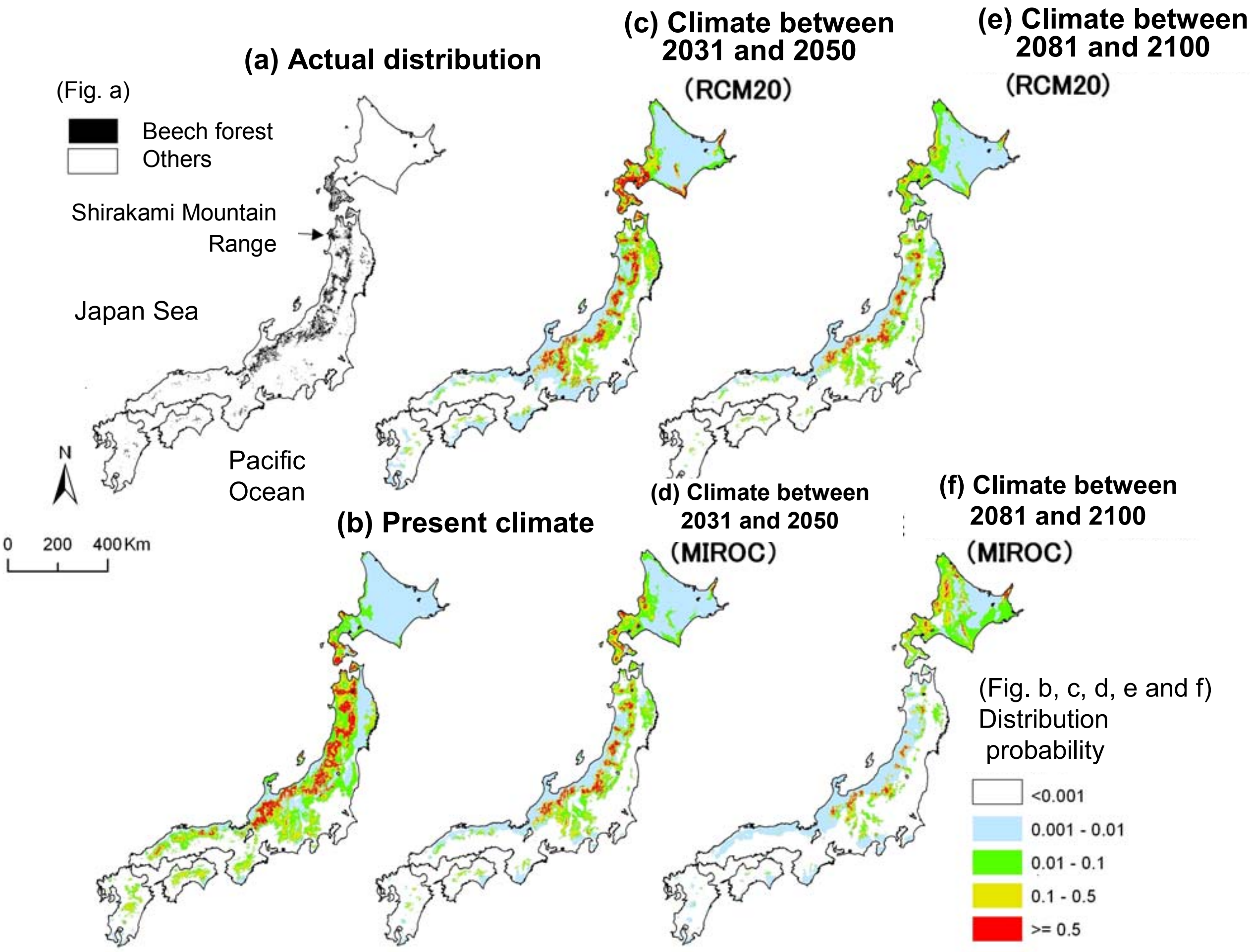


Fig. 4.1.7 Estimate of changes in beech forest distribution probability using climate change projection models RCM20 and MIROC

Source: GERF S-4, 2008

(5) Food

Adverse impacts of climate change on food, such as lower quality of rice and fruits, have already occurred. Future trends of change in rice yields, change in suitable land to grow fruit (move to higher altitudes) and change in suitable habitat of migratory fish are projected.

For the impacts on food, there are some positive impacts, e.g., productivity of some crops will increase due to a higher concentration of CO_2 in the air. But higher temperatures, and more frequent heavy rain and droughts, due to climate change will bring about lower quantity and quality of agricultural crops. Higher seawater temperatures are also thought likely to bring about a change in fish habitats.

Globally, abnormal weather damages agricultural production. According to the IPCC AR4, in mid- and high-latitude regions, if the average temperature increases 1–3°C, there is some crops and areas in which productivity is expected to be slightly higher. However, in the low-latitude regions, especially tropical areas with dry seasons, if the temperature rises slightly (by about 1–2°C), productivity will be lower. The risk of famine is therefore expected to be higher.

[Column 9] Impacts of climate change on ecosystems

Climate change cases particular impacts on ecosystems and biodiversity. Since biological events include interactions between organisms, impacts on ecosystems and biodiversity are more difficult to assess than impacts on other systems. If the number of a certain type of animal decreases due to climate change, the number of organisms that those animals eat is likely to increase, and conversely the number of other animals that eat that animal is likely to decrease. In addition, it is also important to note that impacts of climate change often become more serious due to human behavior. For instance, climate changed changes in the ecosystem of lakes due to climate change becomes more severe due to water pollution. If human use of land disrupts ecosystems, it will disturb the migration of organisms, and organisms are expected to be in danger of extinction.

There are many irreversible changes in organisms or ecosystems, so they have only limited adaptability. Since extinct organisms can never be restored to life, some functions of ecosystems will be irreversibly lost. On the other hand, even if some species became extinct, some functions of ecosystems will still remain.

Dispersal rate depends on the organism. For organisms which are more mobile, such as birds and insects, the dispersal rate is high. For organisms which are not mobile and have a long life, such as trees, the rate is low. As a result, trees may lose their symbiotic partners that carry their pollen or seeds. If changes in such phenomena continue as a result of climate change, a brand new combination of species may create a new ecosystem. In addition, since the projected rate of change in climate is higher than for other environmental change rates that organisms have experienced, the current climate change rate could exceed the inherent dispersible rate of an organism. Organisms on Earth have experienced a living condition in which the average temperature was 2°C higher than the one about 6,000 years ago. Therefore, they are likely to avoid extinction if the temperature rise is within this range, but if the temperature rise exceeds this range, it is difficult to project if they will survive. Furthermore, since the distribution of organisms is likely to be determined by a low or high temperature that occurs only once in many years, it is difficult to project their survivability using only the average temperature.

Forests and agricultural ecosystems created by humans are adaptable because they can be replaced by different types of trees and crops. However, adaptation measures for natural ecosystems are limited. If we can clearly project that a function of an ecosystem will be damaged, human interactions are required. In this case, we need to decide which function of the ecosystem should be a priority.

In Japan, many impacts of climate change have been confirmed. For agriculture, both whitish immature rice grains (milky white-brown rice) (Fig. 4.1.8) and cracked rice grains, decline in yields, and abnormal coloration of fruits (oranges and grapes) have been reported. For cattle, a decline in the quantity and quality of their milk, lower quality of meats and lower reproductive efficiency has been reported (Ministry of Agriculture, Forestry and Fisheries of Japan, 2009). For fisheries, an increase of tropical seaweeds in the sea area around Kyushu, and a late growth of cultivated algae caused by lower seawater temperature in fall have also been reported.

Fig. 4.1.9 shows the results of estimates as to how higher temperatures and higher CO_2 concentrations in the air will change rice yields in the future. These are based on a global climate model, MIROC (Emission scenario: SRESA1B) (GERF S-4, 2008). If measures such as shifting the rice planting time are not taken, in the period from 2046 to 2065, compared to the current state (1979 to 2003), the rice yield in northern Japan, is projected to increase, while in western Japan the rice yield will be the almost same as the current one or slightly lower. In the period between 2081 and 2100, the impacts of climate change will intensify, and the areas where rice yields decline will spread in the Chugoku and Kyushu regions. Moreover, considering factors such as a change in water reserves in the snowing season and effects of diseases and pests, even in areas where the crop yield is expected to increase, shown in the figure on the right of Fig. 4.1.9, it is possible that the yield may decrease.

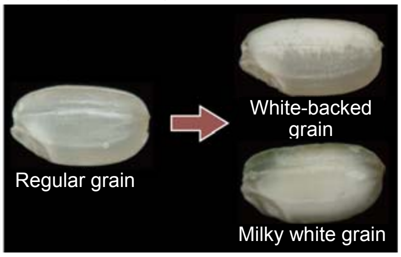


Fig. 4.1.8 Lower quality rice grains such as whitish immature grains

Courtesy: Satoshi Morita, Senior researcher, National Agricultural Research Center for Kyushu Okinawa Region

Regarding fruits, if the increasing in temperature exceeds 3°C, almost all of Hokkaido will become a suitable area to grow apples, but flatlands in the central Tohoku region and areas south of the Kanto region will become unsuitable for growing apples (Fig. 4.1.10).

For Unshu oranges (Satsuma mandarin), if the rise of temperature exceeds 3°C, the suitable area will spread to the coastal area of the southern Tohoku region. On the other hand, the current major production centers are projected to be unsuitable areas for growing oranges (Fig. 4.1.11).

In terms of impacts on fisheries, the suitable habitat for salmon around Japan will decrease. In 2050, even in the Sea of Okhotsk, there will be no area with suitable temperatures. In terms of impacts on cultivation, the suitable area for farming Torafugu puffer fish will move toward the northern part of Japan, and it will become possible to farm them in the Hokuriku and Tohoku regions (Kuwahara, et al., 2006).

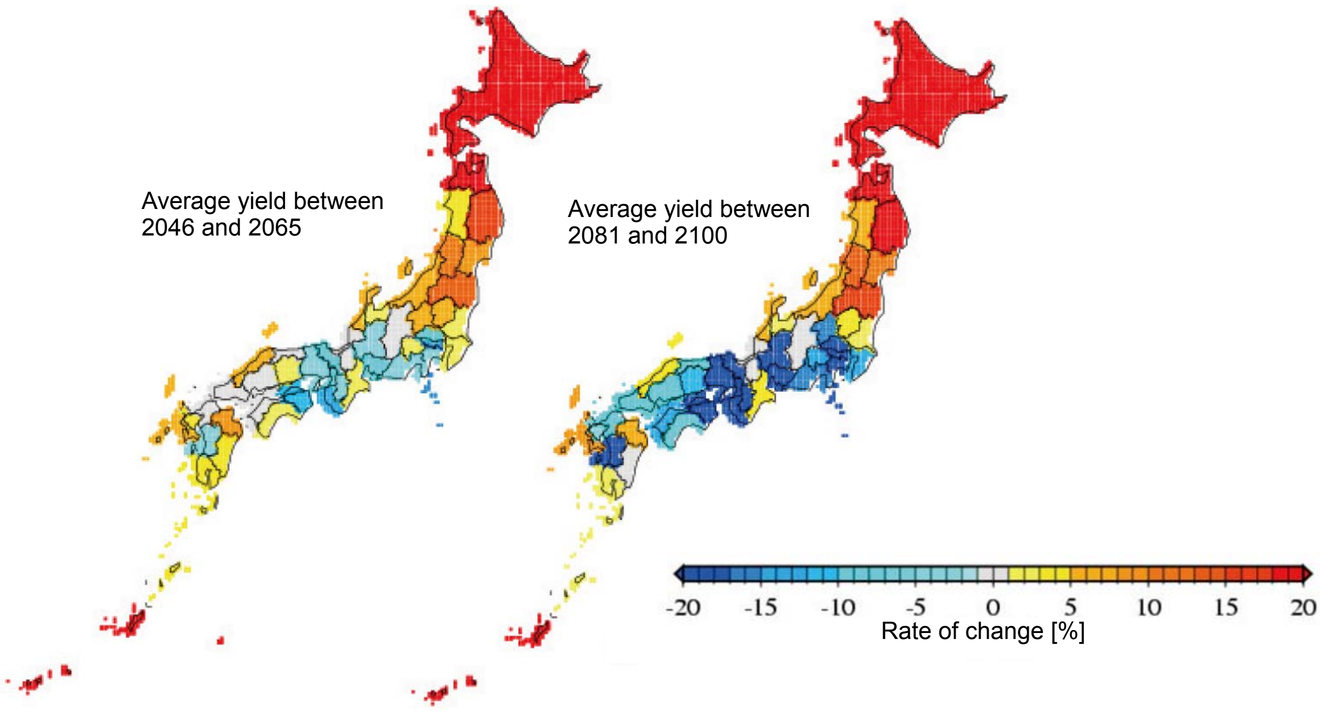


Fig. 4.1.9 Estimated change in rice yield

Source: GERF S-4, 2008

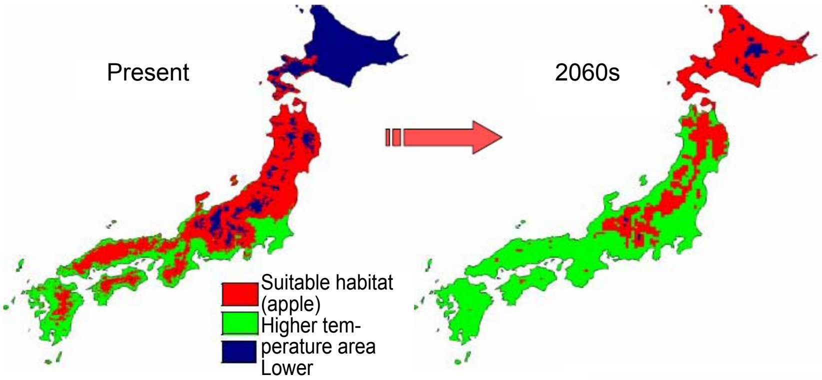


Fig. 4.1.10 Shift in areas suitable for growing apples

Results are for a temperature rise of about 3°C by the 2060s, relation to the temperature in 1980.

Source: Sugiura & Yokozawa, 2004

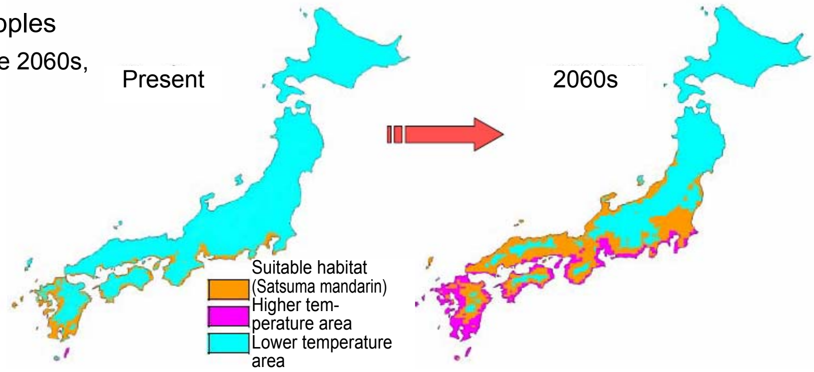


Fig. 4.1.11 Shift in areas suitable for growing Unshu oranges

Results are for a temperature rise of about 3°C by the 2060s, relation to the temperature

Source: Sugiura and Yokozawa, 2004

If climate change continues as anticipated it might have a serious impact on food supply all over the world. Since Japan depends on imports for more than half of its food supply, there is need to consider such possible impacts. For example, in Australia, due to the drought that occurred in 2006, wheat production decreased by approximately 60% over the previous year and Australia's export of wheat was reduced to about two-thirds. Since Japan is dependent on Australia for about 20% of its imported wheat, Japan was significantly affected by rising retail prices of food products using wheat.

(6) Health

Heat stroke has increased, and the distribution area of vectors carrying infectious diseases pathogens has changed. It is expected that in the future heat stress-related mortality risk will increase, the number of people suffering from heat stroke will increase, and the distribution area of vectors carrying pathogens will expand.

Impacts of climate change on human health are roughly classified into two groups: one is direct impacts of heat and the other is indirect impacts of heat, such as increase of infectious diseases, air pollution, large natural disasters and hygiene pests.

The IPCC AR4 identifies some signs of regional impacts of climate change, such as an increase in heat-related deaths and a change in the distribution of vectors carrying pathogens which affect human health, claiming the confidence rate is 50%[41]. For malaria, which is prevalent in many part of the world, it is projected that 220 million to 400 million people will face the risk of malaria. In some Asian countries, by 2030 the malnourished population will increase, while in Canada vectors (ticks) transmitting Lyme disease will expand northwards by 1,000 km by 2080. Climate change brings about some benefits, such as a decreased number of people dying from cold, but on the whole it is projected that the negative impacts of higher temperature on human health will exceed the positive impacts, especially in developing countries.

In many cities of Japan, a record number of people suffered from heat stroke (emergency transporting to hospitals) in 2007. An increase in the number of heat stroke patients has been reported. As shown in Fig. 4.1.12, considering at the distribution of Aedes albopictus (Asian tiger mosquito), which transmits dengue virus, Tochigi Prefecture was its northern limit in 1950. But its range has expanded northwards, and in the 2000, it was confirmed that the mosquito had expanded to the northern Tohoku region (Kobayashi, M. et al., 2008).

In the future, with a rise in temperature, especially a rise in the daily highest temperatures, the heat stress-related mortality risk and the number of heat stroke patients will dramatically increase. In particular, the risk for elderly persons is expected to be higher. In terms of heat stress-related mortality risk, and compared to the period between 1981 and 2000, if the temperature rises about 1.0°C, the risk will become 1.6 times higher, and if the temperature rises about 1.7°C, it will be 2.2 times higher. Accordingly, one estimate says that the damage will cost[42] 27.4 billion yen/yr and 52.9 billion yen/yr, respectively (GERF S-4, 2009).

[41] "Confidence rate" shows the level of uncertainty regarding the correctness of the IPCC AR4 models, analysis and opinions, based on expert judgment. The term "the confidence rate is medium" means "about 5 out of 10 are correct".

[42] The amount willing to pay to avoid the increase of death risk (to maintain the current state). Medical costs are not included.

For vectors carrying pathogens, it is assumed that the distribution of Aedes albopictus (Asian tiger mosquito) transmitting dengue fever virus will spread in Japan, and Aedes aegypti will enter Japan. If an infectious disease occurs and becomes prevalent overseas due to climate change, the virus will reach Japan through travelers.

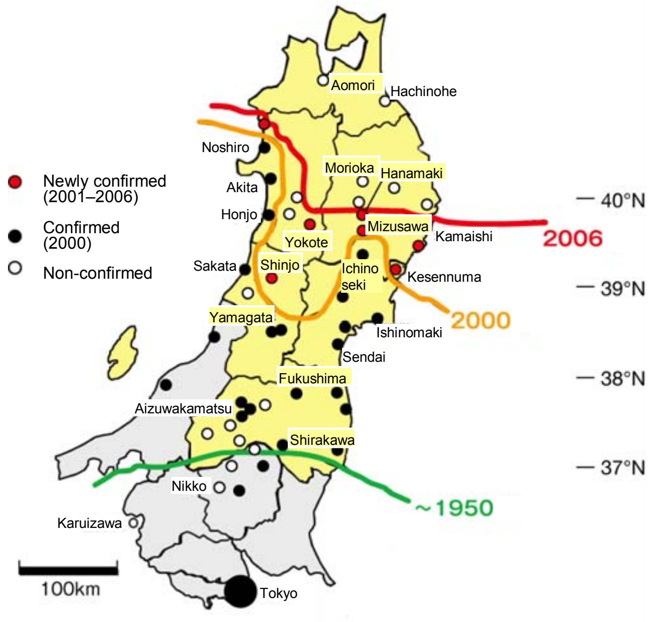


Fig. 4.1.12 Change of the northern limit of Aedes albopictus' distribution in the Tohoku region
Source: Kobayashi, M. et al., 2008

(7) Human Well-being and Urban Life

Changes in the natural environment and weather conditions have impacted on traditional events, tourism and sports events such as skiing. The following impacts are projected: further discomfort caused by extremely hot days and sweltering nights, increase of household costs caused by long air conditioner operating hours and impacts on regional culture caused by snow shortages and change in the time when cherry trees are in bloom.

Impacts of climate change on our lives will include: houses damaged by flood disasters, impacts on health such as heat stroke, water shortages including droughts, decrease in income caused by impacts on industries, discomfort feeling caused by sweltering nights, and damage to sightseeing resources and cultural assets. An increase in household costs caused by long operating hours of air conditioners, a change of our seasonal dietary habit and natural scenery, less opportunities for sightseeing, sports and recreation and impacts on traditional events caused by a change in the cherry blossom season have been identified. For example, in Lake Suwa in Japan there is an interesting natural phenomenon called o-miwatari. The lake has a natural hot spring under its surface, so that even when the top freezes in winter, the lower waters are still warm and circulating. This results in pressure ridges forming in the ice, reaching heights of 30 cm or more. However, the condition of there being no ice on the surface of the lake, and consequently no o-miwatari, has frequently occurred since 1951. Climate change has affected traditional events as well.

It has been confirmed that snow shortages has affected winter sports. In Japanese ski areas, it has been estimated that if the temperature rises 3°C, most ski areas, other than those in the high-altitude Chubu region and Hokkaido, will suffer from a 30% or more decrease in the number of customers (Fig. 4.1.13).

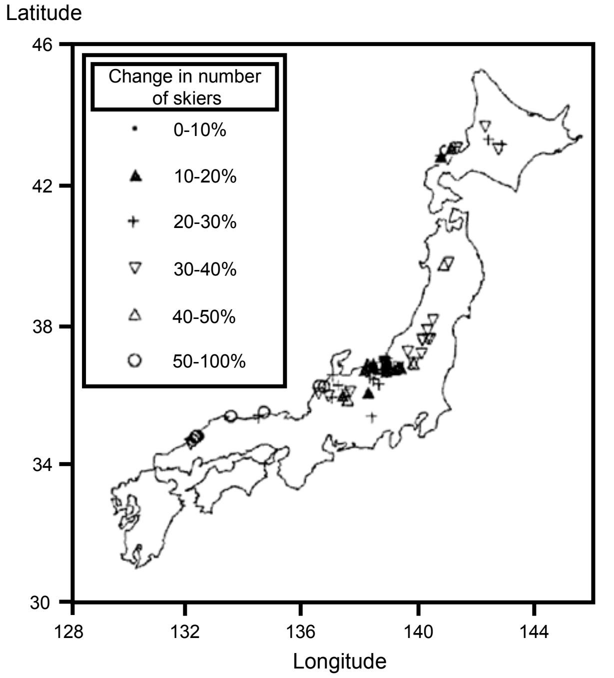


Fig. 4.1.13 Example of estimated decline in the number of skiers

In Japanese ski areas; there is a positive correlation between snow depth and the number of skiers. For each ski area, an equation was created between snow depth and the number of skiers, and used to calculate the impact of a projected change in snow depth caused by a rise in the average temperature on the number of skiers, in percentage terms.

Source: Fukushima et al., 2002

4.2 Adaptation to future climate change – What adaption measures are required?

(1) Needs for adaptation

In response to the projected adverse impacts of climate change, adaptation measures need to be implemented in conjunction with mitigation measures.

As described above, Japan is already experienced many negative impacts of climate change. In the future, for various aspects of our lives, impacts of climate change are expected to increase. On the other hand, for instance, if a significant reduction of GHG emissions can slow the increase in temperature between the Industrial Revolution and the end of the 21st century to about 2°C, the impact is expected to be considerably reduced. However, the projection also shows that a certain level of damage will still be unavoidable (GERF S-4, 2009.

The IPCC AR4 pointed out that we can decrease, slow or avoid impacts of climate change by reducing GHG emissions (mitigation measures). However, in terms of impacts for the next few decades, it is essential that we implement adaptation measures. Neither adaptation measures nor mitigation measures can completely prevent all impacts. Both measures each other and can reduce the risks of climate change.

Based on our understanding about how best to address the projected adverse impacts of climate change, it is essential to implement adaptation measures together with mitigation measures.

(2) Foundations for adaptation

To effectively and efficiently implement adaptation measures, it is important to integrate the viewpoint of adaptation into existing relevant policies and plans, and to introduce adaptation measures in a manner that always ensures certain flexibility, taking into account the uncertainty of impact projections.

When considering adaptation measures, it is important to assess the vulnerability of the location, region and country in question. Japan is developed in terms of science, technology and social infrastructure, and has a relatively high adaptive capacity. On the other hand, Japan has its own unique vulnerabilities derived from its natural and social characteristics including frequent occurrence of floods and landslides caused by typhoons, frequent occurrence of earthquakes, high dependence on imported food and resources, and aging demographic structure. If such vulnerabilities are amplified by the impacts of climate change, it may have enormous influences and threaten the social stability and safety in Japan.

Appropriate assessment of regional vulnerability can clarify areas where urgent measures are required, and enable effective and efficient adaptation. Figure 4.2.1 shows an example of schematic diagram for regional vulnerability assessment. In vulnerability assessments, the interests of general public such as safety and health need to be fully assessed. The first step should be to monitor the impacts of climate change to find out the current situation. Following impact monitoring, for effective and efficient adaptation measures, it is important to incorporate the viewpoint of adaptation into various existing relevant policies and plans such as urban, agricultural and environmental policies and plans. Taking into account the uncertainty of impact projection, adaptation measures should be introduced in a manner that ensures a certain allowance while making the best use of available monitoring results as well. A co-benefit[43] type of adaptation measures should be promoted where certain mitigation effects or benefit to the local environment, society and economy can also be expected.

(3) Approaches and specific measures for adaptation

Japan is making various efforts incorporating the viewpoint of adaptations. It is important to enhance these individual efforts, and to move forward with combined mitigation and adaptation measures in a comprehensive way.

Many government agencies and institutions are already implementing a variety of specific measures

[43] For example, greenery is not only adaptation measures but also beneficial measures including mitigation (reduction of green house gas emission), watershed protection, biodiversity protection and amenity improvement.

incorporating the viewpoint of adaptation. Some examples are as follows:

○Water Environment and Water Resources

Adaptation measures to address impacts and damages due to droughts including an emergency water supply system, and risk reduction measures by using rainwater and recycled water.

○Water-related Disasters and Coastal Areas

Adaptation measures by enhancing facilities such as river improvements to respond to increased precipitation and preparation of facilities to handle floods; adaptation measures integrated with local development such as flood control measures together with land use regulation and guidance adaptation measures focusing on emergency response by forecasting and warning measures including restoration and recovery from large disasters, flood forecasts and early warning information for landslide disasters; flood control measures including enhanced sewerage facilities, and discharge control measures: measures to respond to risks of disasters caused by sea-level rise in harbor areas; and monitoring aiming to detect climate change.

○Natural Ecosystems

Monitoring of diversified ecosystems nationwide, measures against damages by diseases and pests in forests; forest conservation measures.

○Food

Shift of planting timing to avoid high temperatures during the grain filling period or improvement of brand, as measures against high-temperature damage to rice; measures to prevent insufficient coloring of vegetables and fruits caused by high temperatures and strong sunshine by providing covers to block sunlight; introduction of high-temperature-resistant brands.

○Health

Approaches and measures to prevent heat stroke; monitoring and surveillance on infectious-disease vectors and outbreak of infectious diseases.

○Human Well-being and Urban Life

Greening of facilities, use of water retentive materials and highly reflective paints, and development of wind path routes and waterways which alleviates heat island phenomena.

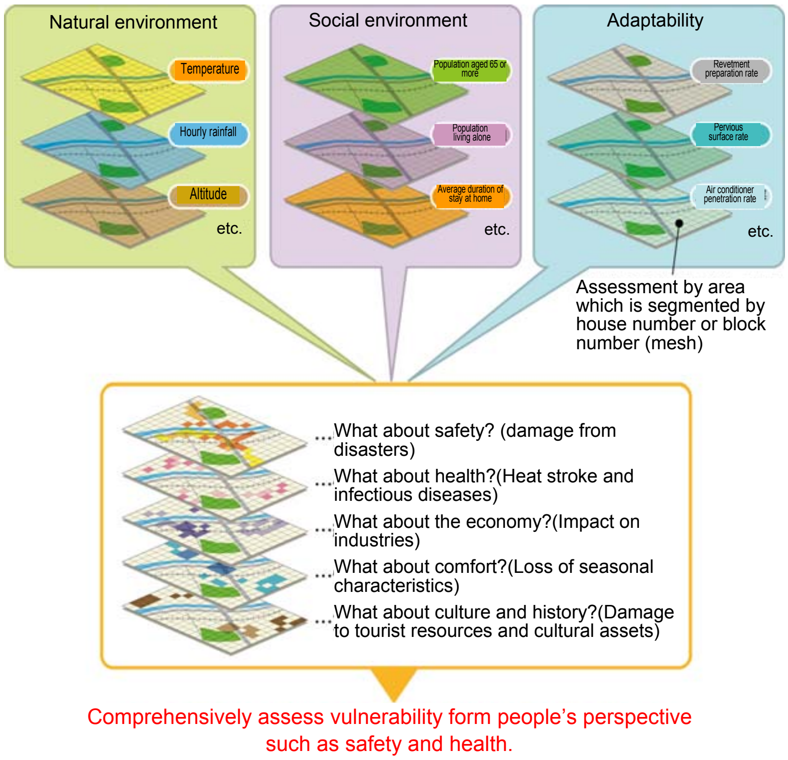


Fig. 4.2.1 Assessment of vulnerability in each community (example)

Source: MOE et al., 2009

In the future, these efforts should be enhanced. In addition, it is necessary to reinforce the adaptation measures by combining a selection of various hard and soft technologies and policies, and the reforms of social and economic systems, and incorporate the viewpoint of adaptation into a wide range of sectors in the society — so-called mainstreaming of adaptation.

At present, Japan is facing not only climate change but also various other challenges such as an aging demographic structure and population decrease. Therefore, it is important to comprehensively advance measures responding to these challenges by incorporating mitigation and adaptation measures into efforts for creating secured, safe and richer local societies. Figure 4.2.2 shows a conceptual example of a society in which mitigation and adaptation measures have been integrated. For example, in urban areas it is important to take measures against heat island phenomena such as introducing super-heat-insulated buildings and a disaster-resistant and efficient public transportation network. In rural areas, it is important to improve CO_2 sequestration by appropriate management and conservation of forests, promote functions to preserve national land and effective use of biomass[44] resources, and establish forestry and agricultural technique to ensure food safety, mitigation and adaptation at the same time. Moreover, it is necessary to create a social infrastructure to enable each and every individual to take proactive actions to adapt to climate change, such as preventing heat stroke with a community-wide initiative, in order to protect ourselves from disasters. A low-carbon society aims to mitigate climate change by the reduction of CO_2 emissions. A climate-resilient society has a structure enabling adaptation to impacts of climate change. It is necessary to make every effort at both national and local levels to realizing a low-carbon and climate-resilient society where mitigation and adaptation are integrated.

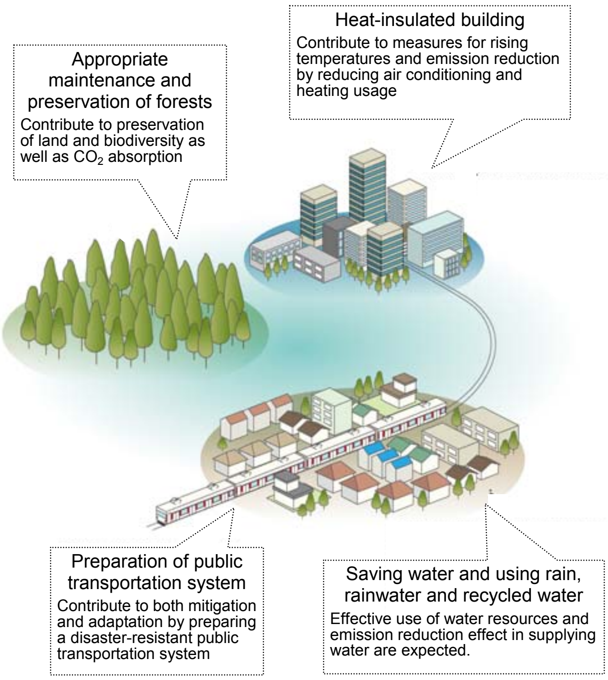


Fig. 4.2.2 A society in which both mitigation and adaptation are integrated (example)

Source: MOE et al., 2009

[44] Renewable and biological resources except fossil resources. Waste-oriented biomass includes waste paper, domestic animal wastes, food wastes, construction-derived wood wastes, black liquor and sewage sludge.

5. Approaches to the observations and projection of climate change and impact assessment, as well as future visions – What information and knowledge is made available in the near future?

The following approaches are implemented to more appropriately assess environmental impacts and draw up adaptation measures by accurately monitoring and projecting climate change as mentioned above, as well as for climate change observation and projection and impact assessment;

(1) Initiatives for observation

To discuss climate change issues and project future climate change, it is necessary to correctly understand the reality of climate change and related mechanism such as relations between air flow or CO_2 and the climate system. To that end, the following efforts are being advanced: steady continuous observation (monitoring) to accumulate data intensive observation, research observation to discover mechanisms; and development of new observation technologies.

Japan has constantly and systematically observed the weather and ocean since the end of the 19th century. The results have helped us significantly in forming a detailed picture of long-term climate change. Since such systematic, continuous, and steady observations provide materials can from the basis of climate change projection and countermeasures, the enhancement and continuity of these activities is promoted through international collaboration. In particular to ascertain the CO_2 accumulation in the ocean (data that is essential for climate change projection), a global ocean CO_2 observation project is being underway while Japan is also enhancing its observation network.

Scientific findings gleaned from observations of the global environment form the foundation for knowledge and technologies necessary in responding to climate change. We have learned much ever since new observation technologies such as satellites and

Argo floats were introduced at the end of the 20th century; matters relating to including ocean heat distribution and the decrease of sea ice in general, as well as in snow and ice area in the Arctic Ocean are now understood. It is still difficult to accurately project the balance of CO_2 as contributed by terrestrial vegetation and marine ecosystems. Therefore, at present, the CO_2 balance (flux) is under observation and being studied utilizing an observation tower that is installed in forests. Ocean CO_2 is also under observation and study utilizing devices installed in observation boats and private cargo boats; a small CO_2 observation drifting buoy is also being developed and studied (Fig. 5.1).

The concentration of GHGs, including CO_2 is measured at various observation points around the world (Fig. 5.2, see Section 2.4 of this report), but there are still areas lacking any observation points. In January 2009, Ibuki, the world's first advanced GHG observing satellite (GOSAT, Fig. 5.3), was launched, to observe the distributions of CO_2 and methane concentrations over the entire Earth along with their variation over time. Utilizing complementary ground-based observations, we expect the satellite to measure CO_2 emissions and sinks by region. In addition, various approaches are being advanced: CO_2 observations utilizing private regular flights; development of a new observation equipment (LIDAR) which observes the vertical distribution of CO_2 using lasers; and the promotion of sharing observation data through a global framework.

Fig. 5.1 Developing a small drifting buoy system with sea surface CO_2 sensors
Courtesy: JAMSTEC

Through these efforts, climate change and global warming is being observed constantly. We expect to discover the mechanism of climate change, upgrade projection models, and formulate more appropriate climate change countermeasures utilizing observation results obtained thusly.

Fig. 5.2 Minamitorishima (CO_2 observation)
Courtesy: JMA

Fig. 5.3 GHG Observing satellite "Ibuki" (GOSAT)
Courtesy: Japan Aerospace Exploration Agency

(2) Initiatives for projection

Understanding of the movements/variations in mechanisms of the global-scale atmosphere (temperature, wind, cloud, precipitation, and radiation) and oceans (water temperature and current) has progressed through precise analysis of data accumulated through the observations activities described in the previous section. As a result, the states of the atmosphere and ocean can be expressed in figures, and progress was achieved in the development of a climate change projection model by modeling these movements. With the appearance of high-performance supercomputers, it has become possible to run future climate change simulations with unprecedented accuracy. Japan has significantly contributed to pulling together IPCC AR4 through research utilizing the climate change projection model.

However, as indicated in IPCC AR4, the current climate change projection model contains uncertainties regarding the effects of clouds and aerosol as well as carbon circulation feedback, which have significant effects on projection results.

These problems must be resolved, and more accurate, reliable projection results must be provided to IPCC AR5 (to be released in 2013 or 2014). We now require further effects for contributing to the formulation of more appropriate adaptation and migration measures for climate change.

To respond to these issues, we are working on the calibration of more accurate global warming projections utilizing high-performance computers such as the Earth Simulator (the world's most advanced supercomputer), to calculate uncertainties in the projection quantitatively; projections of extreme phenomena (typhoons and torrential rain) as effects of global warming of recent public concern; and studies for climate change projection considering movements of substances other than CO_2. We are also moving forward with research and development that meets the themes of projecting long-term climate change (until 2300); predicting the near future (20 to 30 years hence); and projecting extreme phenomena (typhoons and torrential rain) as required by IPCC AR5 (Fig. 5.4).

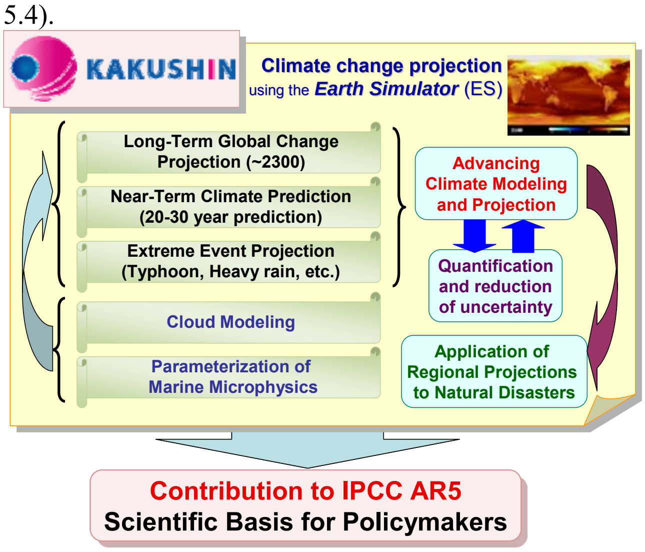


Fig. 5.4 Innovative Program of Climate Change Projection for the 21st Century (KAKUSHIN Program)

To project trends in global warming and abnormal weather, as well as future changes in prominent phenomena, we are developing a highly accurate regional climate model that includes the effects of geography such as major mountains, valleys, and plains with a horizontal resolution of several kilometers (Fig. 5.5).

By providing global warming projection results to domestic and foreign study groups involved in impact assessment and adaptation measures, through these research projects, we expect significant progress in studies on mitigation and adaptation measures for global warming.

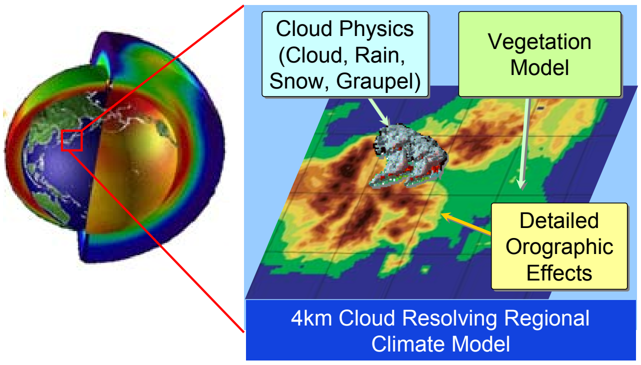


Fig. 5.5 Development of high-performance regional climate model

(3) Initiative for impact assessment

As shown in Chapter 4, climate change impact monitoring has been implemented in each field in various ways. As a result, in Japan, a variety of phenomena have been detected which are likely to be caused by climate change. In considering the assessment of vulnerability to climate change and adaptation measures, it is extremely important to monitor actual impacts so that it is necessary to continuously and systematically implement the monitoring focusing on detecting climate change impacts and their long-term change.

With respect to climate change impacts prediction, it has become possible to quantify relations between major impacts in each sector and temperatures rise. For some impact items, it has even become possible to estimate the extent of damage in a monetary term based on a certain scenario. However, at present, some challenges still remain. For example, detailed impact projections at sub-national and local levels have not been achieved due mainly to the resolution of climate change projection models; impact projections with a probability range based on multiple models are not fully available, the assessment techniques of vulnerability and adaptation effects are not standardized, and policy-relevant research on concrete adaptation measures of national and local governments are not sufficient both in terms of quantity and quality. In the next five years, there are strong expectations for the emergence of practical scientific knowledge which can be used to consider adaptation measures at the national and local government level. More specifically, it is expected that the following scientific knowledge become available (Fig. 5.6):

- Projections of national-wide impacts taking uncertainties into account and their downscaling[45] to the prefectural government level by developing highly accurate and high-resolution up-to-date climate change models and impact assessment and projection models, and also developing probabilistic impact projection techniques based on multiple climate projection results.
- Quantifications of changes in impacts according to different emission scenarios and adaptation scenarios.
- Development of easy-to-use assessment techniques to assess vulnerabilities, impacts, adaptation effects and adaptation policy development techniques which are applicable to local governments or developing countries.
- Establishment of techniques to develop comprehensive adaptation policies (integration with mitigation measures, response to aging society and co-benefits with local revitalization) taking into account uniqueness and existing circumstances of local governments.

Researchers of arts and social sciences need to participate in these studies in carrying out socioeconomic reviews and in developing policy proposals. In addition to research per se, it is required to promote close communication with local governments, business communities and civil society, and encourage each group to take action to enhance adaptation measures and realize a low-carbon and climate-resilient society.

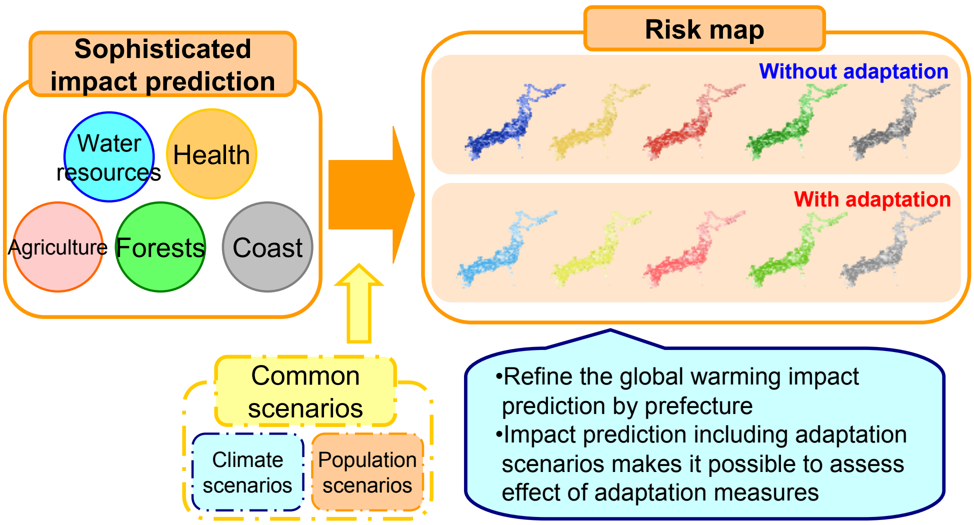


Fig. 5.6 Scheme for the future climate change impact projection research (example)

45 A technique to create higher resolution information from results of global projection models to project a regional or local climate change.

6. Conclusions

According to the long-term observation results, the temperature in Japan has risen approximately 1.1°C in the last 100 years. Observed increasing heavy rainfall over the last century and decreasing alpine plant communities, which are a vulnerable ecosystem, are likely attributable to climate change. According to the results of a climate change projection utilizing a supercomputer, if GHGs are not reduced global level (as shown in Section 3.2), the average temperature in Japan will rise by approximately 2–4°C by the end of the 21st century, and, subsequently, a wide range of climate changes such as an increased number of extremely hot days may occur. Such changes may have significant impacts on various sectors closely related to our lives, and as shown in Section 4.1, the total damage from floods; landslides; loss of beech tree habitats; loss of beaches; damage caused by storm surge in western Japan; and heat stress-derived mortality risks may amount to almost 17 trillion yen annua1ly by the end of the 21st century (present value, no discounting applied).

To prevent such changes to the climate and the resulting impacts, we need to strengthen GHG emission reduction efforts immediately, and continuously reduce a significant amount of emissions over the long-term- - as in over the next 50 to 100 years. To realize such a policy, a voluminous degree of scientific knowledge is essential to support any policymaking. Additional supplementary information to interpret such of information and knowledge, including the uncertainty of projection, is also important. The latest information and knowledge pulled together into this report caters to such needs. However, climate change-related information and knowledge is expected to cover a wider scope and be more accurate. In the future, we need to provide the latest information and knowledge and make continuous efforts to interpret and explain them meaningfully.

Acknowledgements

In preparing this report, we received a great deal of cooperation from many people. Especially, we would like to express our gratitude to the following organizations and individuals: the expert committee led by Shuzo Nishioka, Senior Visiting Researcher of National Institute for Environmental Studies (NIES); and the JMA’s Advisory Group of the Council for Climate Issues led by Hiroki Kondo, Principal Scientist, Global Warming Projection Research Project for IPCC AR5, Japan Agency for Marine-Earth Science and Technology (JAMSTEC). In providing data, giving instructions about how to use data, and reviewing reports, Kazuya Yasuhara, Professor of Department of Urban and Civil Engineering, College of Engineering, Ibaraki University; Yukihiro Nojiri, Deputy Director, Center for Global Environmental Research (CGER), NIES; Toshinobu Machida, Chief, Office for Atmospheric and Oceanic Monitoring, CGER, NIES; Kiyoshi Takahashi, Senior researcher of Climate Risk Assessment Research Section, CGER, NIES; Hideo Shiogama, Special researcher of Atmospheric Environment Division, NIES; Yasuaki Hijioka, Senior researcher of Integration Assessment Section, Social and Environmental Systems Division, NIES; Masao Ishii, Senior Researcher, The Second Research Laboratory, Geochemical Research Department, Meteorological Research Institute; and Toshihiko Sugiura, Research Leader of Research Team for Global Warming on Fruit Trees, National Institute of Fruit Tree Science, National Agriculture and Food Research Organization. In addition, we received cooperation from the Cabinet Office, Ministry of Agriculture, Forestry and Fisheries of Japan, and Ministry of Land, Infrastructure, Transport and Tourism in the checking of the content of this report.

Glossary

[A]

Albedo

Ratio of solar radiation reflecting from a surface to solar radiation falling on the surface

Adaptation measures

Measures to coordinate how nature or human society should be to cope with ongoing or possible climate change, and reduce the negative impacts of such climate change.

Area Map of Japan (as reference)

[C]

Climate sensitivity

Climate sensitivity shows the global average surface air temperature variation against the unit radiative forcing. Generally, it means the equilibrium temperature rise of global annual average temperature caused by doubled CO_2 concentration. In short, it is an equilibrium surface temperature variation under the radiative forcing caused by doubled CO_2 concentration after adequate time has passed.

Climate sensitivity differs depending on the climate projection model, and is a major parameter of projection uncertainty. The IPCC AR4 says, from the results of the equilibrium test using each country's climate model, "It is likely to be in the range 2°C to 4.5°C with a best estimate of about 3°C."

Climate system

The atmosphere directly impacts on climate change. Changes in oceans, land surface, snow and ice are deeply involved in variations of air and water circulation. Therefore, the atmosphere, ocean, land surface, snow and ice are treated as a system, which is called a "climate system."

[E]

El Niño/La Niña

El Niño is a condition that the sea surface temperatures in the central and eastern equatorial Pacific continue to be higher than normal for more than 6 months.

La Niña is a condition that the sea surface temperatures in the central and eastern equatorial Pacific continue to be lower than normal for more than 6 months.

[G]

GHG: Greenhouse Gas

Greenhouse gases which absorb infrared radiation from the Earth's surface such as the sea and land and emit it again. The main greenhouse gases are CO_2, methane, dinitrogen monoxide and halocarbon.

Carbon dioxide (CO_2) is a colorless, odorless and noncombustible and chemically stable gas. There is a strong absorption band in the 15 µm wavelength infrared region, which has a strong greenhouse effect. According to IPCC AR4, the radiative forcing by CO_2 increased since 1750 is 1.66 [1.49–1.83] W/m^2, and it increased 20% in the period from 1995 to 2005. Of the radiative forcing caused by increased long-life greenhouse gases, it is thought that CO_2 accounts for about 63%.

Methane (CH_4) is a colorless, odorless and combustible gas. There is a strong absorption band in the 8 µm wavelength infrared region, which efficiently absorbs and emits infrared radiation. The radiative forcing per molecule in the current atmospheric composition is about 25 times stronger than that of CO_2. The radiative forcing by CH_4 increased during the period from 1750 to 2005 is 0.48 [0.43–0.53] W/m^2, which is thought to account for 18% of the total radiative forcing caused by increased long-life greenhouse gases (IPCC, 2007).

Dinitrogen monoxide (N_2O) is a colorless gas and is very stable in the troposphere. There is a strong absorption band in the 8 µm wavelength infrared region, which has a strong greenhouse effect. The radiative forcing by N_2O increased during the period after the Industrial Revolution to 2005 is 0.16 [0.14–0.18] W/m^2, which is thought to account for 6% of the total radiative forcing caused by increased long-life greenhouse gases (IPCC, 2007).

Halocarbon is a generic name for carbon compounds containing fluorine, chlorine, bromine and iodine, which are halogen atoms. Originally, most of them did not exist in nature but were industrially produced. In general the concentration of halocarbons is very low in the atmosphere. However, since they have a strong greenhouse effect even in a low concentration, the radiative forcing by halocarbon increased during the period from 1750 to 2005 is assumed to be 0.34 [0.31–0.37] W/m^2, which accounts for 13% of the total radiative forcing caused by increased long-life greenhouse gases (IPCC, 2007).

[I]

IPCC (Intergovernmental Panel on Climate Change)

An organization established by the World Meteorological Organization (WMO) and UN Environment Programme (UNEP) in 1988, aiming to comprehensively assess anthropogenic climate change, impacts and adaptation and mitigation measures, from scientific, technological, social and economic standpoints. It has issued four assessment reports (the latest AR4 was released in 2007) and played an important role in providing a scientific proof to global efforts for global warming including UNFCCC.

[K]

Kyoto Protocol

It was adopted at COP3 for the United Nations Framework Convention on Climate Change (UNFCCC) in December 1997. For greenhouse gas emissions, legally binding numerical goals are determined for industrial countries, and new mechanisms such as emissions trading systems, joint implementation and the clean development mechanism were introduced.

[L]

La Niña

See “El Niño /La Niña.”

[M]

Mitigation measures

Measures to control greenhouse gas emissions.

[P]

PDO (Pacific Decadal Oscillation)

The Pacific Ocean has changed in conjunction with the atmosphere in a long cycle of over a decade, which is called "Pacific decadal oscillation." In this climate change, the North Pacific Ocean and the tropical Pacific Ocean slowly have repeated cycles of low and high temperature. Accordingly, the strength of the Aleutian low and Westerlies varies.

[R]

Radiative forcing

It is a scale of impact that a factor has to change the balance of energy which comes in and out of the Earth-atmosphere system. It is an important index of a factor as a potential climate change mechanism. The positive radiative forcing tends to raise the Earth's surface temperature, and the negative radiative forcing tends to reduce the Earth's surface temperature (IPCC, 2007).

[S]

SRES (Special Report on Emissions Scenarios) Scenarios

In IPCC, scenarios from which IPCC projected anthropogenic emissions of greenhouse gases in the 21st century from sociological and economic perspectives.

[U]

UNFCCC (United Nations Framework Convention on Climate Change)

A convention aiming to stabilize greenhouse gases in the atmosphere at a level at which we do not need to make dangerous anthropogenic interference measures with regards to the Earth's climate system. It was adopted at the UN on May 9, 1992. A total of 155 countries including Japan signed up for it during the UN Conference on Environment and Development.

[V]

Vulnerability

How easily something is impacted by adverse effects of climate change such as global warming and extreme phenomena, and how unable it is to respond to adverse effects. For example, in terms of effects of heat, generally elderly people have high heat stroke and mortality risks and are vulnerable.

[W]

WMO (World Meteorological Organization)

WMO was established based on the Convention of the World Meteorological Organization in 1950, and became the specialized agency of the United Nations in 1951. Its vision is to provide world leadership in expertise and international cooperation in meteorological, hydrological and related environmental issues. WMO has a membership of 182 countries and six regions as of March 2009. The WMO Secretariat has its Headquarters in Geneva, Switzerland.

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List of members of the Expert Committee on "Synthesis Report on Observations, Projections, and Impact Assessments of Climate Change"

(As of Sept. 2009)

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