Climate Change in Japan

Report on Assessment of Observed/Projected Climate Change Relating to the Atmosphere, Land and Oceans

December 2020

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

Japan Meteorological Agency (JMA)

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Introduction

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Background legislation/decisions

- Paris Agreement prescribing a review of related progress every five years (Global Stocktake) to help the Parties update their Nationally Determined Contributions (NDCs)
- Climate Change Adaptation Act (Act No. 50, 13 June 2018)
  → Climate Change Adaptation Plan (Cabinet Decree, 27 November 2018)
  → Assessment Report on Climate Change Impact in Japan (December 2020)
- MEXT & JMA have operated an advisory board for their climate change services since FY2018.
  → Based on input from the MEXT/JMA Advisory Board on climate change services (established in FY 2018), the *Climate Change in Japan* assessment report was published in December 2020. A projection dataset is also to be produced in 2022 for updates on physical science expertise and further contribution to climate-related action in Japan.

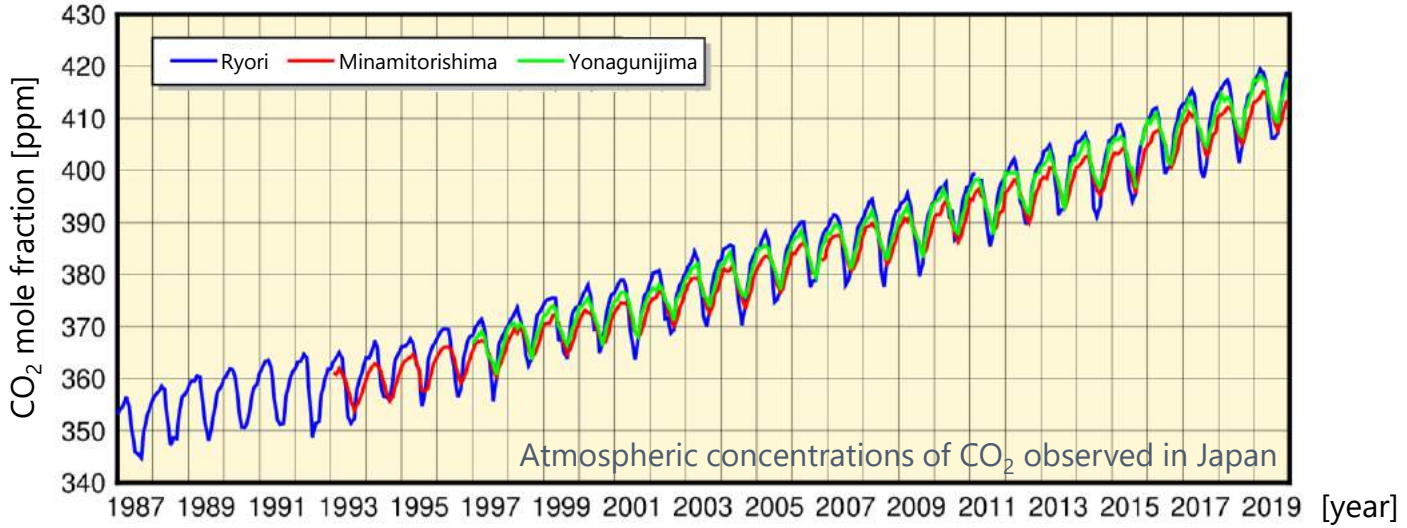
Details of *Climate Change in Japan* (2020)

- The report provides basic information contributing to climate change mitigation and adaptation / impact assessment for Japanese national/local government bodies, commercial enterprises and the public.
- It covers the status of atmospheric greenhouse gases (GHGs) and observed/projected changes in climate variables (e.g., surface/sea surface temperature, precipitation and sea levels) in and around the country.
- Climate conditions are generally projected under the RCP2.6 and 8.5 scenarios (referred to as the 2°C and 4°C Warming Scenarios in the report), corresponding to potential climatic conditions **with achievement of the Paris Agreement's 2°C target** and **with no future additional mitigation measures**, respectively.
- For certain long-term tendencies and projections, levels of confidence and uncertainty are indicated.
- In addition to the main publication, a separate detailed version is provided for climate change professionals/researchers and as additional reference.
- The main publication provides an overview of the latest physical scientific expertise on climate change in and around Japan, serving as an essential resource for related services and research.
- The chapter structure corresponds to individual climate components, allowing reference at any point based on the area of interest (e.g., a GHG section on the causes of climate change, and a snow-related section for reference to news on mild winter conditions).
- This guide provides a breakdown of the report and outlines its background and characteristics.

Atmospheric GHGs

Observed changes

- Atmospheric concentrations of greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) exhibit increasing trends in relation to human activity.
- There is an increasing trend in downward infrared radiation from the atmosphere corresponding to the intensity of the greenhouse effect caused by GHGs.



IPCC AR5/WG I report (2013)

- Atmospheric concentrations of GHGs have increased since 1750 due to human activity.
- Concentrations of CO_2, CH_4 and N_2O have increased to levels unprecedented in the last 800,000 years or more. Mean rates of increase in atmospheric concentrations over the past century are unprecedented in the last 22,000 years.

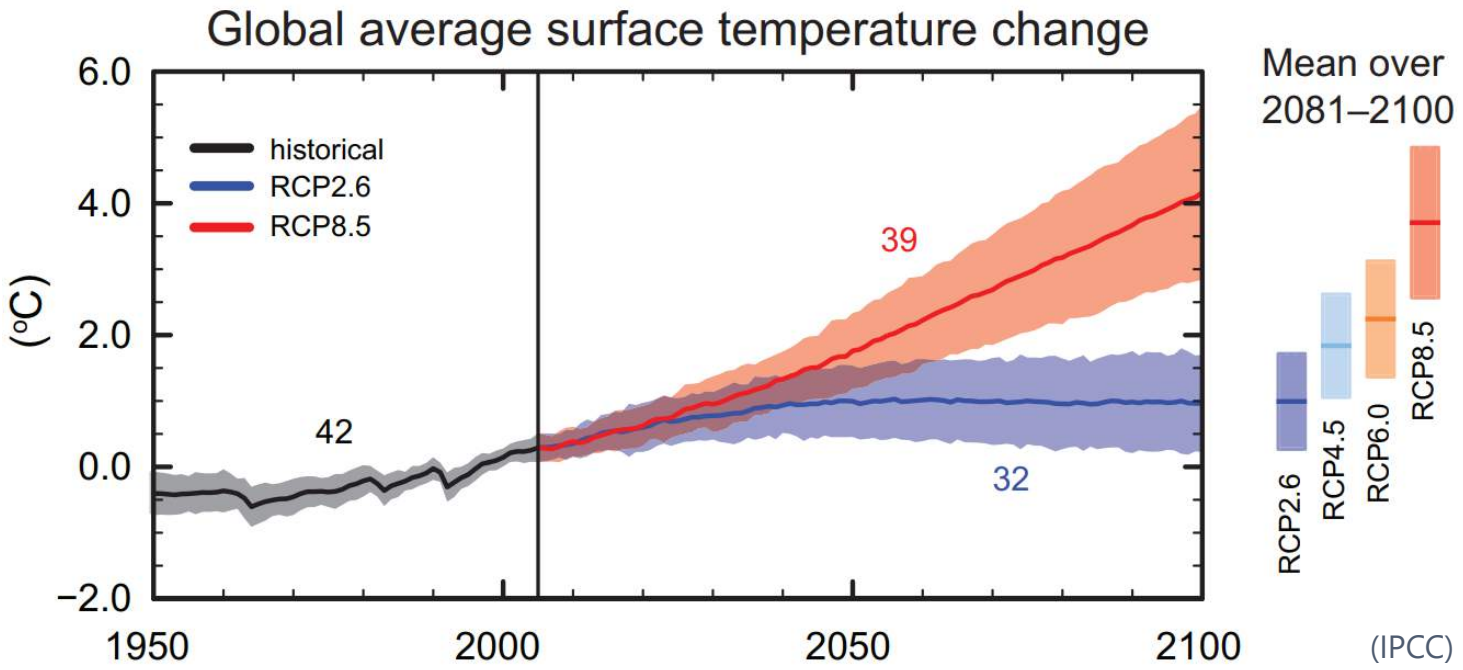
WMO Greenhouse Gas Bulletin No. 16 (2020)

- Globally averaged surface mole fractions for CO_2 reached a new high in 2019 at 410.5 ± 0.2 ppm, corresponding to 148% of pre-industrial levels.
- The mean annual absolute increase from 2010 to 2019 was 2.4 ppm/year (1.5 times that of the 1990s).

2/4°C Warming Scenarios

- Climate projections are based on the **2**/**4**°C Warming Scenarios (**RCP2.6** and **RCP8.5**, respectively).
- Under the **2°C Warming Scenario**, the global average surface temperature is likely to have risen by 0.9 – 2.3°C by the end of the 21st century* from the pre-industrial level (0.3 – 1.7°C from the end of the 20th century*).
  ➡ This corresponds to potential climatic conditions **with achievement of the Paris Agreement's 2°C target**.
- Under the **4°C Warming Scenario**, the global average surface temperature is likely to have risen by 3.2 – 5.4°C by the end of the 21st century* from the pre-industrial level (2.6 – 4.8°C from the end of the 20th century*).
  ➡ This corresponds to potential climatic conditions **with no future additional mitigation measures**.

* Averaged over 1986 – 2005 and 2081 – 2100, respectively



(IPCC)

Projection of Japanese Climate Conditions for the End of the 21st Century under the 2/4°C Warming Scenarios

*The term "**projections**" refers to **averages over Japan at the end of the 21st century** relative to the **end of the 20th century** or **present**, unless otherwise stated.*

Projected values here are expressed as "approx. XX" based on averages, while the report itself shows values with specific uncertainty ranges.

Surface Temperature

Observed changes

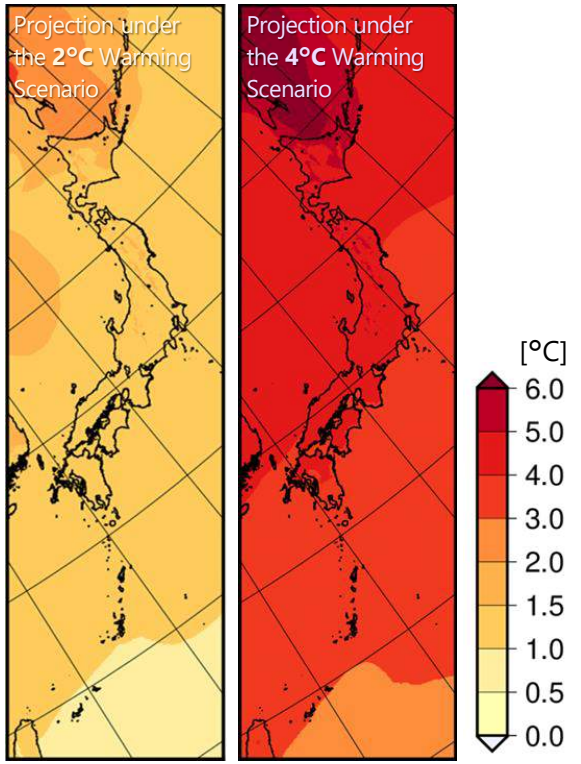
- The annual surface temperature over Japan (based on data from 15 observation stations considered to be relatively uninfluenced by urbanization) increased at a rate of 1.24°C per century between 1898 and 2019.
- Between 1910 and 2019, the annual numbers of days with maximum temperatures of ≥ 30 and ≥ 35°C and minimum temperatures of ≥ 25°C (referred to here as T_{max} ≥ 30°C, T_{max} ≥ 35°C and T_{min} ≥ 25°C days, respectively) have increased, while those of days with minimum temperatures of < 0°C (referred to here as T_{min} < 0°C days) have decreased. In particular, the number of T_{max} ≥ 35°C days has increased significantly since the mid-1990s.

Projections

	2°C Warming Scenario Potential conditions with achievement of the Paris Agreement's 2°C target	**4°C Warming Scenario** Potential conditions with no future additional mitigation measures
Annual surface temperature over Japan	Approx. 1.4°C increase	Approx. 4.5°C increase
Annual global average surface temperature	Approx. 1.0°C increase	Approx. 3.7°C increase
T_{max} ≥ 35°C days per year	Approx. 2.8-day increase	Approx. 19.1-day increase
T_{min} ≥ 25°C days per year	Approx. 9.0-day increase	Approx. 40.6-day increase
T_{min} < 0°C days per year	Approx. 16.7-day decrease	Approx. 46.8-day decrease

- Under both scenarios, the annual surface temperature over Japan for the end of the 21st century is expected to increase, with more T_{max} ≥ 35°C / T_{min} ≥ 25°C days and fewer T_{min} < 0°C days in many regions.
- The temperature increase over Japan is greater under the 4°C Warming Scenario than under the 2°C Warming Scenario.
- Under the same scenario, higher latitudes correspond to greater increases in temperature. Values are also higher in winter than in summer.

Projections are averages over Japan for the end of the 21st century relative to the end of the 20th century or present, unless otherwise stated.



Changes in annual surface temperature for the end of the 21st century (2076 – 2095 average) relative to the end of the 20th century (1980 – 1999 average)

Precipitation

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Observed changes

- While the frequency of daily and hourly extreme precipitation has increased in Japan, that of wet days has decreased (both statistically significant).
- No statistically significant long-term trend is observed in annual or seasonal precipitation over Japan.

Projections

	2°C Warming Scenario Potential conditions with achievement of the Paris Agreement's 2°C target	**4°C Warming Scenario** Potential conditions with no future additional mitigation measures
Annual number of days with precipitation ≥ 200 mm	Approx. x 1.5 increase	Approx. x 2.3 increase
Annual number of events with precipitation ≥ 50 mm/h	Approx. x 1.6 increase	Approx. x 2.3 increase
Annual maximum daily precipitation	Approx. 12% (15 mm) increase	Approx. 27% (33 mm) increase
Annual number of days with precipitation < 1.0 mm	No statistically significant change	Approx. 8.2-day increase

Precipitation ≥ 50 mm/h is torrential rainfall rendering umbrellas useless and creating spray that impairs visibility.

- The frequency and intensity of daily and hourly extreme precipitation over Japan are expected to increase, while those of wet days are expected to decrease.
- No statistically significant change in annual precipitation over Japan is projected.
  There is significant uncertainty in projections on regional and prefectural scales.
- The precipitation system associated with the *Baiu* (seasonal rain) front in June is expected to intensify and be south of its normal location.
  The projection for July is characterized by significant uncertainty.

Projections are averages over Japan for the end of the 21st century relative to the end of the 20th century or present, unless otherwise stated.

Snowfall and Snow Depth

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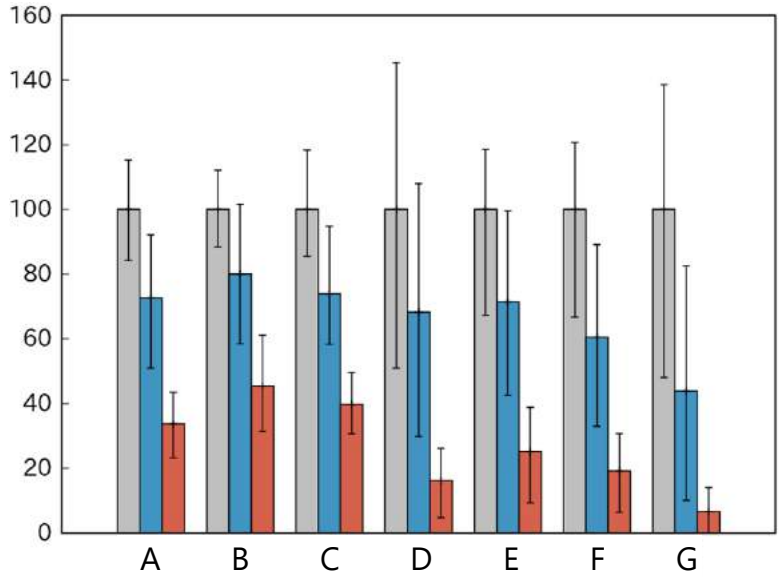
Observed changes

- Data collected at observation stations on the Sea of Japan side of the country indicate that:
  - the annual maximum snow depth in winter has decreased; and
  - the annual number of days with snowfall ≥ 20 cm has decreased.

Projections

	2°C Warming Scenario Potential conditions with achievement of the Paris Agreement's 2°C target	**4°C Warming Scenario** Potential conditions with no future additional mitigation measures
Annual maximum snow depth and snowfall	Approx. 30% decrease (except Hokkaido and certain other areas)	Approx. 70% decrease (except some areas of Hokkaido)
Snowfall period	/	Shorter (delayed start, early end)
Heavy snowfall (decadal max. in the present climate)	/	Potential increase in Honshu mountainous areas and Hokkaido inland areas

- Outside inland Hokkaido, snowfall and snow depth are expected to decrease as global warming progresses, with a higher likelihood of rain.
- Reduced snowfall amounts do not necessarily correspond to reduced risk of exceedingly rare incidences of extremely heavy snowfall. It should be noted that the confidence level of this projection is low.



Maximum snow depth in winter for the end of the 21st century (2076 – 2095 average) standardized by that for the end of the 20th century (1980 – 1999 average) for A) all Japan; B) Sea of Japan side of northern Japan; C) Pacific side of northern Japan; D) Sea of Japan side of eastern Japan; E) Pacific side of eastern Japan; F) Sea of Japan side of western Japan; and G) Pacific side of western Japan. Grey, blue and red bars represent 1) observations for the end of the 20th century, and projections for the end of the 21st century under the 2) 2°C and 3) 4°C Warming Scenarios, respectively.

Projections are averages over Japan for the end of the 21st century relative to the end of the 20th century or present, unless otherwise stated.

Typhoons (Tropical Cyclones)

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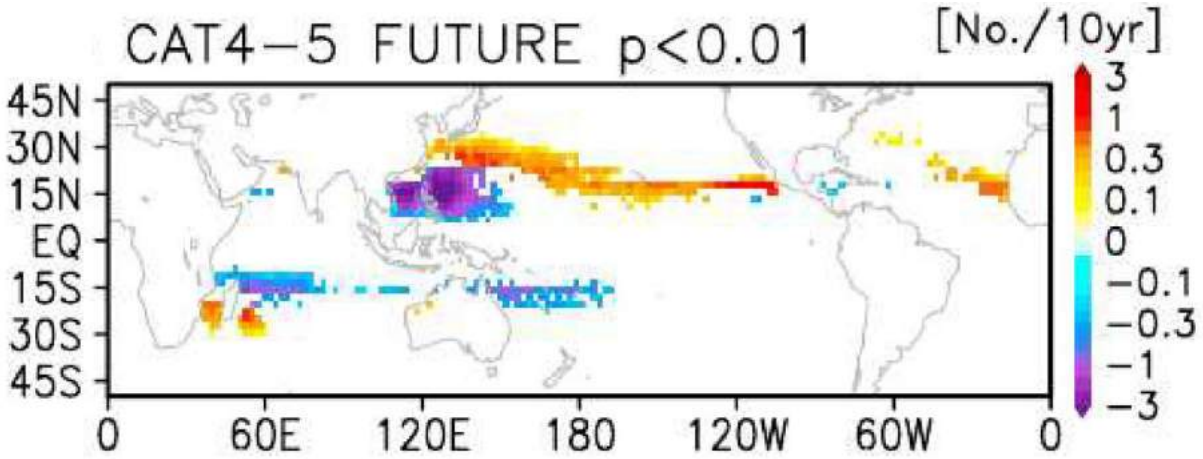
Observed changes

- No long-term trend is observed in the number of typhoons approaching or making landfall on Japan.
- No long-term trend is observed in the number of strong typhoons or in their percentage among all typhoons.
- In and around Japan, the latitude of maximum typhoon intensity exhibited a northward shift.

Projections

- Numerous researchers have projected increased typhoon intensity in the Japan area due to greater amounts of atmospheric water vapor, which is the driving force behind typhoons.
- The results of 4°C warming simulations and other studies indicate high potential for increased occurrence frequency* of intense category 4 – 5 tropical cyclones over waters south of Japan.

* The number of typhoons expected within a specific area/period



Occurrence frequency deviation from recent climate conditions for category 4 – 5 tropical cyclones with 4°C warming (1979 – 2010 average) (Yoshida et al., 2017)

- Globally
  - The intensity of precipitation and wind associated with tropical cyclones (including typhoons) is expected to increase due to greater concentrations of atmospheric water vapor.
  - The number of tropical cyclones is expected to decrease, although further research is needed to establish related confidence.

Projections are averages over Japan for the end of the 21st century relative to the end of the 20th century or present, unless otherwise stated.

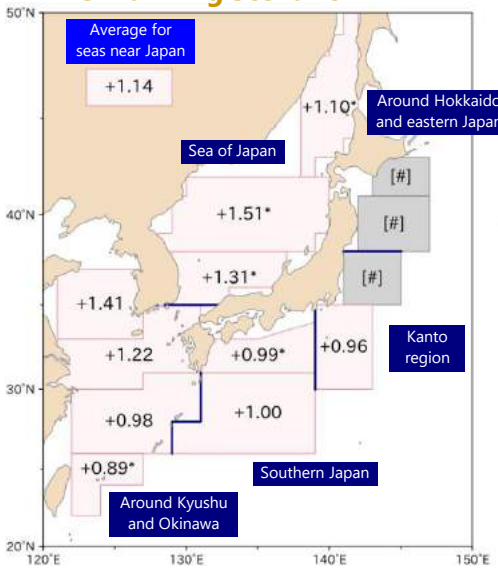
Ocean Temperature

Observed changes

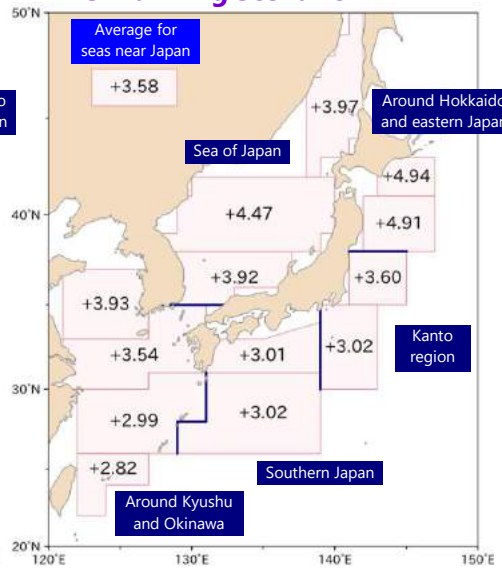
- Averaged sea surface temperatures (SSTs) around Japan increased at a rate of 1.14°C per century between 1900 and 2019.
  - This exceeds the global average of 0.55°C per century. Rates of increase appear relatively high in continental sea areas due to the warming tendency of land and the influence of warm currents.
  - The degree of temperature increase depends on seasonal factors and sea areas.

Projections

Projection under the 2°C Warming Scenario



Projection under the 4°C Warming Scenario



Expected changes in SST for the 2081 – 2100 average relative to the 1986 – 2005 average

Asterisks denote statistical significance at 95% or more. No tendency of statistical significance is observed for hash-marked areas.

	2°C Warming Scenario Potential conditions with achievement of the Paris Agreement's 2°C target	**4°C Warming Scenario** Potential conditions with no future additional mitigation measures
Average SST around Japan	Approx. 1.14°C increase	Approx. 3.58°C increase
Average global SST	Approx. 0.73°C increase	Approx. 2.58°C increase
Average global ocean temperature (depth 0 – 2,000 m)	Approx. 0.35°C increase	Approx. 0.82°C increase

- Under both scenarios, the average SST around Japan for the end of the 21st century is expected to increase.
- SST increase displays non-uniform characteristics, with significant changes in the central part of the Sea of Japan under the 2°C Warming Scenario and in the Kushiro/Sanriku area under the 4°C Warming Scenario.
- Northward displacement of subtropical circulation due to northward shifting of westerly winds may cause SST increase around Japan to exceed the global average. This may lead to high regional SST variability.

Projections are averages over Japan for the end of the 21st century relative to the end of the 20th century or present, unless otherwise stated.

Sea Level, Storm Surges and Extreme Waves

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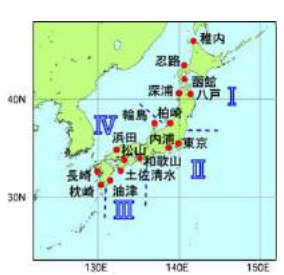
Observed changes

- The global mean sea level (GMSL) increased by 0.16 m between 1902 and 2010 due to melting ice sheets/glaciers and seawater expansion caused by ocean temperature increase. The average rate of sea level rise was 3.6 mm per year between 2006 and 2015, which is approximately 2.5 times that observed between 1901 and 1990.
- A clear trend of sea level rise has been observed since 1980 along the Japanese coast, although some long-period variability (assumed to be natural) is predominant over the whole period.
- No statistically significant long-term trend is observed in the frequency/intensity of storm surges along the Japanese coast.
- The heights of extreme waves along the Japanese coast show an increasing tendency, which is larger on the Pacific side.

Projections

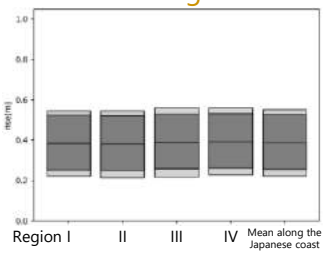
- Under both scenarios, mean sea level rise along the Japanese coast by the end of the 21st century is expected to match the global mean.
- No remarkable difference is observed among projected regional rises except for coastal areas influenced directly by the warm Kuroshio current, where levels are expected to rise slightly.
- The projected sea level rise suggests an enhanced risk of flooding.
- The scale of maximum storm surges in the bays of Tokyo, Osaka and Ise are expected to increase (dependent on typhoon projection).
- Wave heights in decadal-scale events are expected to increase along the Japanese coast (with low confidence due to high uncertainty in the projection of typhoon path changes).

	2°C Warming Scenario Potential conditions with achievement of the Paris Agreement's 2°C target	**4°C Warming Scenario** Potential conditions with no future additional mitigation measures
Mean sea level along the Japanese coast	Approx. 0.39 m increase	Approx. 0.71 m increase
Global mean sea level	Approx. 0.39 m increase	Approx. 0.71 m increase

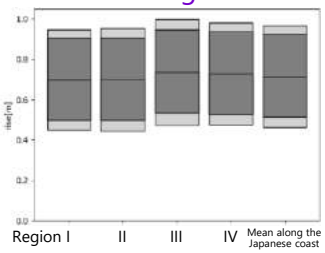


● Sites / I – IV: Regions

Projection under the 2°C Warming Scenario



Projection under the 4°C Warming Scenario



Mean sea level rise along the Japanese coast for the end of the 21st century relative to the end of the 20th century

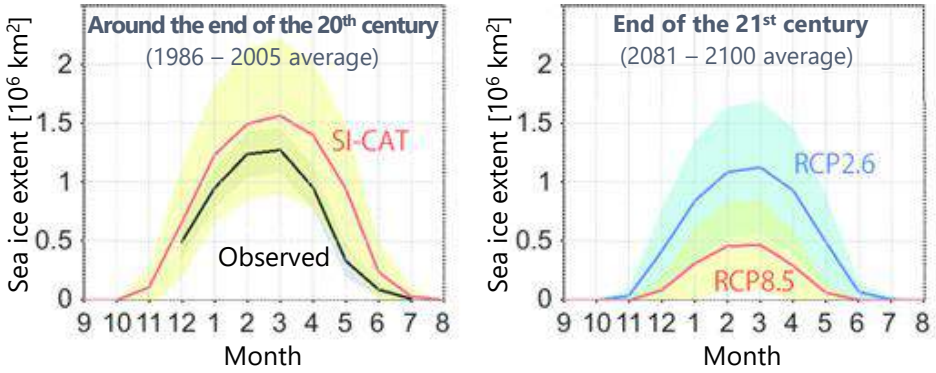
Projections are averages over Japan for the end of the 21st century relative to the end of the 20th century or present, unless otherwise stated.

Sea Ice

Observed changes

- The annual maximum Sea of Okhotsk ice extent decreased at a rate of 61,000 km^2 (equivalent to 5.3% of the normal annual maximum) per decade between 1971 and 2020.
- Observation data for the Japanese coast of the Sea of Okhotsk since 1956 indicate a remarkable reduction in drift ice amounts since the second half of the 1980s.
- The annual minimum Arctic Sea ice extent decreased at a rate of 890,000 km^2 (equivalent to 14% of the normal annual minimum) per decade between 1979 and 2019.
- No statistically significant change is observed in the Antarctic Sea ice extent.

Projections



Seasonal changes in Sea of Okhotsk ice extent

	2°C Warming Scenario Potential conditions with achievement of the Paris Agreement's 2°C target	**4°C Warming Scenario** Potential conditions with no future additional mitigation measures
Sea of Okhotsk ice extent for March	Approx. 28% decrease	Approx. 70% decrease
Arctic Sea ice extent for February	Approx. 8% decrease	Approx. 34% decrease
Arctic Sea ice extent for September	Approx. 43% decrease	Approx. 94% decrease

- The Sea of Okhotsk ice extent in March for the end of the 21st century is expected to decrease under both scenarios, although the reduction under the 2°C Warming Scenario would be within the range of variability in the present climate.
- The amount of sea ice drifting toward the Hokkaido coast is expected to decrease along with reduced sea ice formation along the Siberian coast.
- Arctic Sea ice extent/thickness is highly likely to decrease during the 21st century, falling to practically zero by the mid-21st century under the 4°C Warming Scenario.

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Ocean Acidification

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Observed changes

- Around 30% of anthropogenic CO_2 emitted into the atmosphere is absorbed by oceans, which causes the hydrogen ion exponent (pH) of global surface seawater to decrease at a rate of approx. 0.02 per decade. The global average surface seawater pH is estimated to have decreased by 0.1 since the onset of industrialization.
- Observation data collected from 137°E since 1983 indicate ongoing acidification at a rate similar to the global average (pH values are generally reduced at lower latitudes, where the sea surface temperature is higher).
- A tendency of acidification is also seen along the Japanese coast, with pH values between 1978 and 2009 decreasing by 0.014 and 0.024 per decade in summer and winter (the annual lowest and highest, respectively). These rates are similar to those seen in open seas.

Projections

	2°C Warming Scenario Potential conditions with achievement of the Paris Agreement's 2°C target	**4°C Warming Scenario** Potential conditions with no future additional mitigation measures
Surface seawater pH south of Japan	Approx. 0.04 decrease	Approx. 0.3 decrease
Surface seawater pH (global average)	Approx. 0.065 decrease by the mid-21st century and stable thereafter	Approx. 0.31 decrease
Annual average Ω_{arag} around Okinawa	Ongoing decrease until the mid-21st century 3 or more	Below 3 seasonally in the 2020s – 2030s Below 3 throughout the year after around 2050
Annual average Ω_{arag} south of Japan	Approx. 0.2 decrease	Approx. 1.4 decrease
Annual average Ω_{arag} (global average)	/	Below 3 by 2060 except in low latitudes

- Globally, pH values are expected to fall rapidly in polar and high-latitude regions.
- Aragonite saturation (Ω_{arag}) indicates acidification in the marine ecosystem. Ω_{arag} in high-latitude regions is expected to fall below 3 (a guidance value for significant effects on coral reefs) earlier than in the subtropical zone, even though the rate of decrease is higher in the latter.
- Increasing ocean acidification around Okinawa and southern Japan is expected at a rate similar to that of the global average.

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Projection Summary

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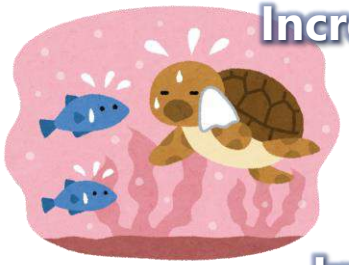
Projected climate conditions for areas in and around Japan
for the end of the 21st century relative to the end of the 20th century or present:

Yellow and purple figures represent the 2°C and 4°C Warming Scenarios (RCP2.6 and 8.5 scenarios), respectively.

Annual Surface Temperature Increase: approx. 1.4 / 4.5°C

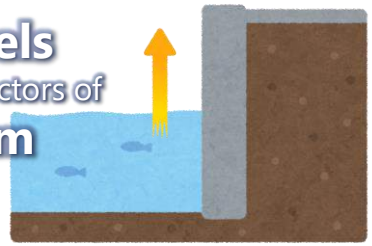
with more T_{max} ≥ 35°C days,
more T_{min} ≥ 25°C days
and fewer T_{min} < 0°C days

Sea Surface Temperature Increase: approx. 1.14 / 3.58°C



The degree of increase is greater than the global average due to geographical characteristics (i.e., greater continental warming than that from ocean and warm currents).

Increased sea levels
along the Japanese coast by factors of approx. 0.39 / 0.71 m



Snowfall and Snow Depth Decrease

Rainfall rather than snow
Ongoing risk of heavy snow

Heavy Precipitation Frequency Increase

Annual maximum daily precipitation increase of approx. 12% (15 mm) / 27% (33 mm)

Precipitation ≥ 50 mm/h event increase by factors of approx. 1.6 / 2.3

Reduced Sea of Okhotsk Ice Extent
in March by approx. 28 / 70%

The Arctic Sea is expected to be practically ice-free by the mid-21st century under the 4°C Warming Scenario.

Proportion of Strong-Typhoon Increase

Increased Wind Speed and Precipitation Associated with Typhoons

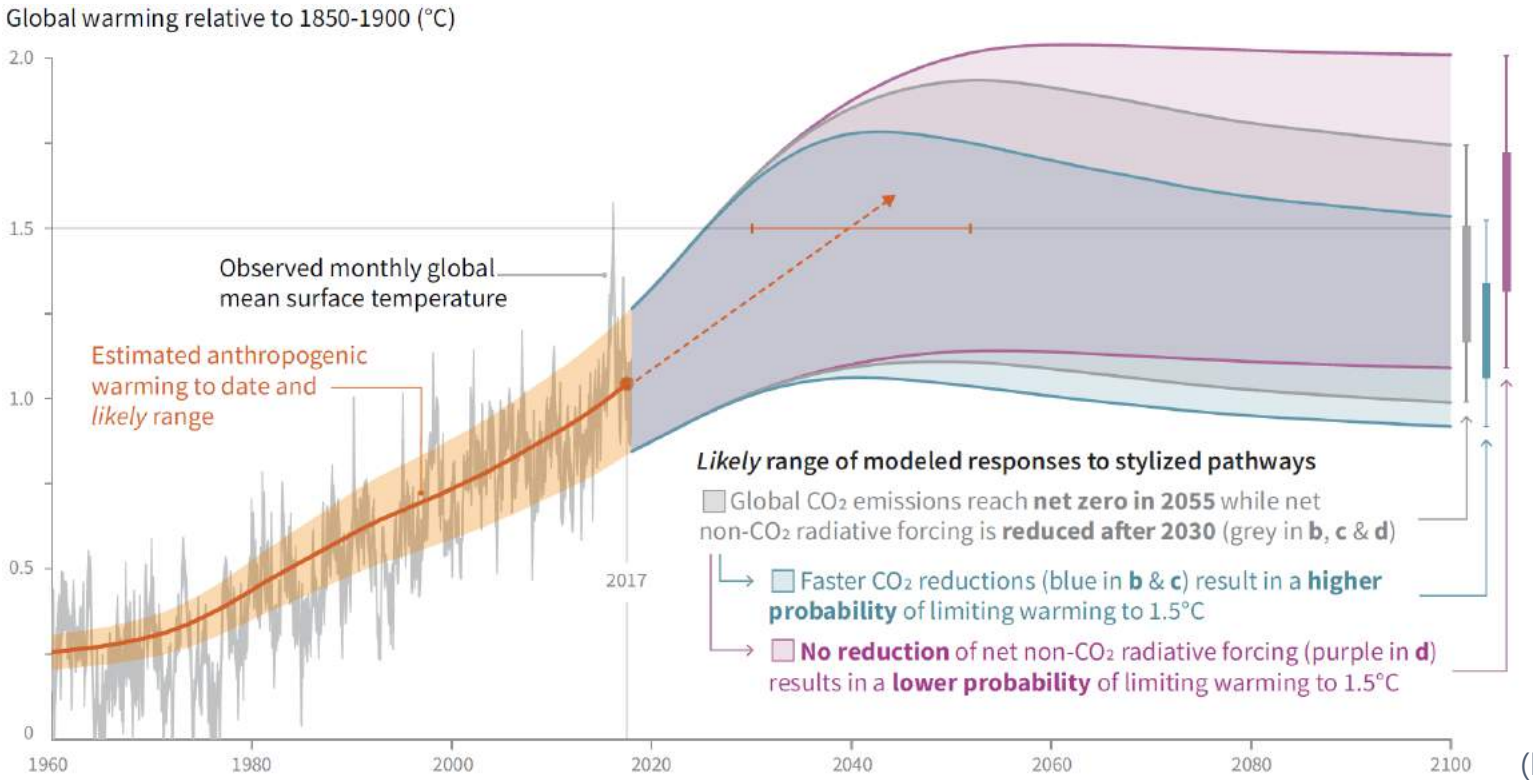
Ongoing Ocean Acidification
around Okinawa and southern Japan
Similar to those of the Global Average

Projections are averages over Japan for the end of the 21st century relative to the end of the 20th century or present, unless otherwise stated.

Supplement

IPCC Special Report on Global Warming of 1.5°C (2018)

- Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate.
- In model pathways with no or limited overshoot of 1.5°C, global net anthropogenic CO_2 emissions decline by approx. 45% from 2010 levels by 2030 (40 – 60% interquartile range), reaching net zero around 2050 (2045 – 2055 interquartile range).
- For limiting global warming to below 2°C, CO_2 emissions are expected to decline by approx. 25% by 2030 in most pathways (10 – 30% interquartile range) and reach net zero around 2070 (2065 – 2080 interquartile range).



(IPCC)