Chapter 2  Climate Change

2.1  Changes in temperature

- The annual anomaly of the global average surface temperature in 2016 was the highest since 1891, and the annual anomaly of the average temperature over Japan was also the highest since 1898.
- On a longer time scale, it is virtually certain that the annual global average surface temperature and the annual average temperature over Japan have risen at rates of about 0.72 and 1.19°C per century, respectively.
- It is virtually certain that the frequency of extremely high monthly temperature events has increased, while the frequency of extremely low monthly temperature events has decreased.
- It is virtually certain that the annual number of days with minimum temperatures below 0°C ($T_{\text{min}} < 0^\circ C$) has decreased, while the annual number of days with minimum temperatures of 25°C or higher ($T_{\text{min}} \geq 25^\circ C$) has increased. The annual number of days with maximum temperatures of 30 °C or higher ($T_{\text{max}} \geq 30^\circ C$) is very likely to have increased, and that with maximum temperatures of 35 °C or higher ($T_{\text{max}} \geq 35^\circ C$) is virtually certain to have increased.

2.1.1  Global surface temperature

The annual anomaly of the global average surface temperature in 2016 (i.e., the combined average of the near-surface air temperature over land and the SST) was +0.45°C above the 1981 – 2010 average. This was the highest since 1891 and the third consecutive annual record. The surface temperature anomalies over the Northern Hemisphere and the Southern Hemisphere were +0.59°C (the highest) and +0.31°C (the highest), respectively (Figure 2.1-1).

The global average temperature fluctuates on different time scales ranging from years to decades. On a longer time scale, it is virtually certain that the global average surface temperature has risen at a rate of about 0.72°C per century

According to IPCC AR5, the global average surface temperature has risen about 0.85°C (The 90% uncertainty interval is 0.65 to 1.06°C) over the period 1880 to 2012. The values given in IPCC AR5 and those in this report are considered to show no remarkable difference that have risen on a longer time scale and are higher since the mid-1990s, although they do not correspond exactly because of differences in dataset calculation methods and the statistical period examined.

12 Monthly, seasonal and annual estimates of average temperatures around the globe and around Japan are published on JMA’s website.
http://ds.data.jma.go.jp/tcc/tcc/products/gwp/gwp.html (English)

13 According to IPCC AR5, the global average surface temperature has risen about 0.85°C (The 90% uncertainty interval is 0.65 to 1.06°C) over the period 1880 to 2012. The values given in IPCC AR5 and those in this report are considered to show no remarkable difference that have risen on a longer time scale and are higher since the mid-1990s, although they do not correspond exactly because of differences in dataset calculation methods and the statistical period examined.

14 For evaluation and clarification of the significance statistics used here, see “Explanatory note on detection of statistical significance in long-term trends” at the end of the report.
natural climate dynamics over different time scales ranging from years to decades. The high temperatures observed in 2016 are considered partially attributable to the El Niño event that persisted from boreal summer 2014 to spring 2016 (Topic I and Section 2.5.1).

Figure 2.1-1 Annual anomalies in surface temperature (i.e., the combined average of the near-surface air temperature over land and the SST) from 1891 to 2016 for the globe (top left), for the Northern Hemisphere (top right) and for the Southern Hemisphere (bottom). Anomalies are deviations from the baseline (the 1981–2010 average). The thin black line with dots indicates surface temperature anomalies for each year. The blue line indicates the five-year running mean, and the red line indicates the long-term linear trend.

Figure 2.1-2 Linear temperature trends for 5° × 5° latitude/longitude grid boxes for the period of 1891 to 2016 (top), and 1979 to 2016 (bottom). The grid boxes with gray circles have no statistically significant trend.
2.1.2 Surface temperature over Japan

Long-term changes in the surface temperature over Japan are analyzed using observational records dating back to 1898. Table 2.1-1 lists the meteorological stations whose data are used to derive annual mean surface temperatures.

Table 2.1-1 Observation stations whose data are used to calculate surface temperature anomalies over Japan

<table>
<thead>
<tr>
<th>Element</th>
<th>Observation stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (15 stations)</td>
<td>Abashiri, Nemuro, Suttsu, Yamagata, Ishinomaki, Fushiki, Iida, Choshi, Sakai, Hamada, Hikone, Miyazaki, Tadotsu, Naze, Ishigakijima</td>
</tr>
</tbody>
</table>

The mean surface temperature in Japan for 2016 is estimated to have been 0.88°C above the 1981 – 2010 average, which is the highest since 1898 (Figure 2.1-3). The surface temperature fluctuates on different time scales ranging from years to decades. On a longer time scale, it is virtually certain that the annual mean surface temperature over Japan has risen at a rate of about 1.19°C per century (statistically significant at a confidence level of 99%). Similarly, it is virtually certain that the seasonal mean temperatures for winter, spring, summer and autumn have risen at rates of about 1.11, 1.38, 1.08 and 1.20°C per century, respectively (all statistically significant at a confidence level of 99%).

It is noticeable from Figure 2.1-3 that the annual mean temperature remained relatively low before the 1940s, started to rise and reached a local peak around 1960, entered a cooler era through to the mid-1980s and then began to show a rapid warming trend in the late 1980s. The warmest years on record have all been observed since the 1990s.

The high temperatures seen in recent years have been influenced by fluctuations over different time scales ranging from years to decades, as well as by global warming resulting from increased concentrations of greenhouse gases such as CO$_2$. This trend is similar to that of worldwide temperatures, as described in Section 2.1.1.

![Figure 2.1-3 Annual surface temperature anomalies from 1898 to 2016 in Japan.](image)
2.1.3  Long-term trends of extreme temperature events in Japan

This section describes long-term trends of extremely high/low-temperature events in Japan, as derived from analysis of temperature records from the 15 observation stations. Though monthly mean temperatures of the stations in Miyazaki and Iida have been adjusted to eliminate the influence of their relocation, records from these two stations are not used for analysis of daily temperatures due to the difficulty of adjustment in regard to the relocation.

(1) Long-term trends of monthly extreme temperatures

It is virtually certain that the frequency of extremely high monthly temperatures has increased, while that of extremely low monthly temperatures has decreased (both statistically significant at the confidence level of 99%) (Figure 2.1-4). These trends are consistent with the rising annual mean temperatures discussed in Section 2.1.2.

![Figure 2.1-4](image_url)

Figure 2.1-4  Annual number of extremely high/low monthly mean temperature occurrences

The graphs show the annual number of occurrences of the highest/lowest first-to-forth values for each month during the period from 1901 to 2016. The green bars indicate annual occurrences of extremely high/low monthly mean temperatures divided by the total number of monthly observation data sets available for the year (i.e., the average occurrence per station). The blue line indicates the five-year running mean, and the straight red line indicates the long-term linear trend.

(2) Annual number of days with maximum temperatures of ≥ 30°C and ≥ 35°C

The annual number of days with maximum temperatures ($T_{\text{max}}$) of ≥ 30°C is very likely to have increased (statistically significant at a confidence level of 90%) and with $T_{\text{max}}$ ≥ 35°C is virtually certain to have increased (statistically significant at a confidence level of 99%) (Figure 2.1-5).

![Figure 2.1-5](image_url)

15 Here, judgment of extremely high/low temperatures is based on the fourth-highest/lowest monthly values on records over the 116-year period from 1901 to 2016. The frequency of occurrence of the highest/lowest to the fourth-highest/lowest values over this period is once every 29 years, which is close to JMA’s definition of extreme climate events as those occurring once every 30 years or longer (See the Glossary for terms relating to Extreme climate event).
(Chapter 2 Climate Change)

Figure 2.1-5  Annual number of days with maximum temperatures of $\geq 30^\circ C$ and $\geq 35^\circ C$

The graphs show the annual number of days per station, with the green bars indicating the values for each year during the period from 1931 to 2016. The blue line indicates the five-year running mean, and the straight red line indicates the long-term linear trend.

(3) Annual number of days with minimum temperatures of $< 0^\circ C$ and $\geq 25^\circ C$

It is virtually certain that the annual number of days with minimum temperatures ($T_{\text{min}}$) of $< 0^\circ C$ has decreased, while the annual number of days with $T_{\text{min}} \geq 25^\circ C$ has increased (both statistically significant at a confidence level of 99%) (Figure 2.1-6).

Figure 2.1-6  Annual number of days with minimum temperatures of $< 0^\circ C$ and $\geq 25^\circ C$

As per Figure 2.1-5.
2.1.4 Urban heat island effect at urban stations in Japan

The long-term trends of annual average temperatures are more pronounced for urban observation stations whose data are homogeneous over a long period (Sapporo, Sendai, Nagoya, Tokyo, Yokohama, Kyoto, Hiroshima, Osaka, Fukuoka, Kagoshima) than for the average of the 15 rural observation stations (Table 2.1-2).

Table 2.1-2 Long-term trends of annual and seasonal average temperatures at urban stations in Japan

These figures are based on data from 1931 to 2016. The trend of the 15 rural station averages (Table 2.1-1) is also listed. Values shown in italics are not statistically significant at a confidence level of 90%. For stations with asterisks (among the 15 rural stations, Iida and Miyazaki), trends are calculated after adjustment to eliminate the influence of relocation.

<table>
<thead>
<tr>
<th>Station</th>
<th>Long-term temperature trend (°C/century)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ann Win Spr Sum Aut Ann Win Spr Sum Aut Ann Win Spr Sum Aut</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sapporo</td>
<td>2.7 3.4 2.9 1.9 2.7</td>
<td>1.0</td>
<td>1.4</td>
<td>1.5</td>
<td>0.7</td>
<td>0.6</td>
<td>4.5</td>
<td>5.7</td>
<td>4.7</td>
<td>3.5</td>
<td>4.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sendai</td>
<td>2.4 3.0 2.8 1.4 2.6</td>
<td>1.2</td>
<td>1.5</td>
<td>1.5</td>
<td>0.9</td>
<td>1.0</td>
<td>3.2</td>
<td>3.7</td>
<td>3.8</td>
<td>2.0</td>
<td>3.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nagoya</td>
<td>2.9 3.0 3.2 2.2 3.2</td>
<td>1.3</td>
<td>1.4</td>
<td>1.6</td>
<td>0.8</td>
<td>1.2</td>
<td>4.0</td>
<td>3.9</td>
<td>4.5</td>
<td>3.2</td>
<td>4.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tokyo*</td>
<td>3.3 4.4 3.3 2.0 3.4</td>
<td>1.7</td>
<td>1.9</td>
<td>1.9</td>
<td>1.2</td>
<td>1.7</td>
<td>4.5</td>
<td>6.0</td>
<td>4.6</td>
<td>2.9</td>
<td>4.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yokohama</td>
<td>2.8 3.5 3.1 1.8 2.9</td>
<td>2.4</td>
<td>2.6</td>
<td>2.8</td>
<td>1.8</td>
<td>2.4</td>
<td>3.6</td>
<td>4.7</td>
<td>3.8</td>
<td>2.2</td>
<td>3.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kyoto</td>
<td>2.7 2.6 3.0 2.3 2.8</td>
<td>1.1</td>
<td>0.8</td>
<td>1.6</td>
<td>1.0</td>
<td>0.8</td>
<td>3.8</td>
<td>3.8</td>
<td>4.1</td>
<td>3.2</td>
<td>4.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hiroshima*</td>
<td>2.0 1.6 2.4 1.6 2.5</td>
<td>1.0</td>
<td>0.7</td>
<td>1.7</td>
<td>1.1</td>
<td>0.5</td>
<td>3.2</td>
<td>2.8</td>
<td>3.4</td>
<td>2.6</td>
<td>3.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osaka*</td>
<td>2.7 2.7 2.7 2.2 3.1</td>
<td>2.2</td>
<td>2.2</td>
<td>2.5</td>
<td>2.0</td>
<td>2.1</td>
<td>3.6</td>
<td>3.3</td>
<td>3.6</td>
<td>3.3</td>
<td>4.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fukuoka</td>
<td>3.1 2.9 3.4 2.2 3.8</td>
<td>1.7</td>
<td>1.6</td>
<td>2.2</td>
<td>1.4</td>
<td>1.7</td>
<td>5.0</td>
<td>4.5</td>
<td>5.9</td>
<td>3.7</td>
<td>6.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kagoshima*</td>
<td>2.8 2.7 3.2 2.3 3.1</td>
<td>1.3</td>
<td>1.2</td>
<td>1.8</td>
<td>1.1</td>
<td>1.3</td>
<td>4.0</td>
<td>3.8</td>
<td>4.6</td>
<td>3.4</td>
<td>4.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 stations*</td>
<td>1.5 1.6 1.9 1.2 1.5</td>
<td>1.1</td>
<td>1.1</td>
<td>1.6</td>
<td>0.9</td>
<td>0.9</td>
<td>1.9</td>
<td>1.9</td>
<td>2.1</td>
<td>1.6</td>
<td>1.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As it can be assumed that the long-term trends averaged over the 15 rural stations reflect large-scale climate change, the differences in the long-term trends of urban stations from the average of the 15 stations largely represent the influence of urbanization.

Detailed observation reveals that the long-term trends are more significant in winter, spring and autumn than in summer and more pronounced for minimum temperatures than for maximum temperatures at every urban observation station.

Records from urban stations whose data are not affected by relocation are used to determine long-term trends for the annual number of days with minimum temperatures of < 0°C and ≥ 25°C and maximum temperatures of ≥ 30°C and ≥ 35°C. The number of days with T_{min} < 0°C has decreased with statistical significance at all urban stations, and the number with T_{min} ≥ 25°C has increased with statistical significance at most stations except Sapporo. Also the number of days with T_{max} ≥ 30°C and ≥ 35°C has increased with statistical significance at most stations except Sapporo (Table 2.1-3).
Table 2.1-3  Long-term trends for the annual number of days with minimum temperatures of < 0°C and ≥ 25°C and maximum temperatures of ≥ 30°C and ≥ 35°C.

These figures are based on data from 1931 to 2016 (1961 to 2016 for maximum temperatures of ≥35°C). The trend of the 13 rural station averages (Table 2.1-1, excluding Iida and Miyazaki) is also listed. Values shown in italics are not statistically significant at a confidence level of 90%.

<table>
<thead>
<tr>
<th>Station</th>
<th>Annual number of days</th>
<th>Trend (days/decade)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T&lt;sub&gt;min&lt;/sub&gt; &lt; 0°C</td>
<td>T&lt;sub&gt;min&lt;/sub&gt; ≥ 25°C</td>
</tr>
<tr>
<td>Sapporo</td>
<td>-4.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Sendai</td>
<td>-5.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Nagoya</td>
<td>-7.1</td>
<td>3.7</td>
</tr>
<tr>
<td>Yokohama</td>
<td>-6.4</td>
<td>3.0</td>
</tr>
<tr>
<td>Kyoto</td>
<td>-7.5</td>
<td>3.6</td>
</tr>
<tr>
<td>Fukuoka</td>
<td>-5.1</td>
<td>4.7</td>
</tr>
<tr>
<td>13 Stations</td>
<td>-2.1</td>
<td>1.7</td>
</tr>
</tbody>
</table>
2.2 Changes in precipitation

- The annual anomaly of global precipitation (for land areas only) in 2016 was +2 mm.
- The annual anomaly of precipitation in 2016 was +212 mm in Japan.
- The annual number of days with precipitation of ≥ 100 mm is virtually certain to have increased, and that with precipitation of ≥ 200 mm is extremely likely to have increased.
  The annual number of days with precipitation of ≥ 1.0 mm is virtually certain to have decreased.

2.2.1 Global precipitation over land

Annual precipitation (for land areas only) in 2016 was +2 mm above the 1981 – 2010 average (Figure 2.2-1), and the figure has fluctuated periodically since 1901. In the Northern Hemisphere, records show large amounts of rainfall around 1930 and in the 1950s. Long-term trends are not analyzed because the necessary precipitation data for sea areas are not available.

![Annual Global Precipitation](image1)

![Annual Northern Precipitation](image2)

![Annual Southern Precipitation](image3)

Figure 2.2-1 Annual anomalies in precipitation (over land areas only) from 1901 to 2016 for the globe (top left), for the Northern Hemisphere (top right) and for the Southern Hemisphere (bottom). Anomalies are deviations from the baseline (the 1981 – 2010 average).
  The bars indicate the precipitation anomaly for each year, and the blue line indicates the five-year running mean.

2.2.2 Precipitation over Japan

This section describes long-term trends in precipitation over Japan as derived from analysis of precipitation records from 51 observation stations (Table 2.2-1).

Annual precipitation in 2016 was +212.3 mm above the 1981 – 2010 average. Japan experienced relatively large amounts of rainfall until the mid-1920s and around the 1950s. The annual figure has become more variable since the 1970s (Figure 2.2-2).

---

16 Data on annual precipitation around the world and in Japan are published on JMA’s website.
Table 2.2-1  List of 51 observation stations whose data are used to calculate precipitation anomalies and long-term trends in Japan

<table>
<thead>
<tr>
<th>Element</th>
<th>Observation stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>Asahikawa, Abashiri, Sapporo, Obihiro, Nemuro, Suttsu, Akita, Miyako, Yamagata,</td>
</tr>
<tr>
<td>(51 stations)</td>
<td>Ishinomaki, Fukushima, Fushiki, Nagano, Utsunomiya, Fukui, Takayama, Matsumoto,</td>
</tr>
<tr>
<td></td>
<td>Maebashi, Kumagaya, Mito, Tsuruga, Gifu, Nagoya, Iida, Kofu, Tsu, Hamamatsu,</td>
</tr>
<tr>
<td></td>
<td>Tokyo, Yokohama, Sakai, Hamada, Kyoto, Hikone, Shimonoseki, Kure, Kobe, Osaka,</td>
</tr>
<tr>
<td></td>
<td>Wakayama, Fukuoka, Oita, Nagasaki, Kumamoto, Kagoshima, Miyazaki, Matsuyama,</td>
</tr>
<tr>
<td></td>
<td>Tadotsu, Tokushima, Kochi, Naze, Ishigakijima, Naha</td>
</tr>
</tbody>
</table>

Figure 2.2-2  Annual anomalies in precipitation from 1898 to 2016 in Japan. Anomalies are deviations from the baseline (the 1981 – 2010 average).

The bars indicate the precipitation anomaly for each year, and the blue line indicates the five-year running mean.

2.2.3  Snow depth in Japan

Long-term trends in the annual maximum snow depth (represented in terms of a ratio against the 1981 – 2010 average) in Japan since 1962 are analyzed using observational records from stations located on the Sea of Japan coast (Table 2.2-2).

Table 2.2-2  Observation stations whose data are used to calculate snow depth ratios in Japan

<table>
<thead>
<tr>
<th>Region</th>
<th>Observation stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea of Japan side of</td>
<td>Wakkanai, Rumoi, Asahikawa, Sapporo, Iwamizawa, Suttsu, Esashi, Kutchan,</td>
</tr>
<tr>
<td>northern Japan</td>
<td>Wakamatsu, Aomori, Akita, Yamagata</td>
</tr>
<tr>
<td>Sea of Japan side of</td>
<td>Wajima, Aikawa, Niigata, Toyama, Takada, Fukui, Tsuruga</td>
</tr>
<tr>
<td>eastern Japan</td>
<td></td>
</tr>
<tr>
<td>Sea of Japan side of</td>
<td>Saigo, Matsue, Yonago, Tottori, Toyooka, Hikone, Shimonoseki, Fukuoka,</td>
</tr>
<tr>
<td>western Japan</td>
<td>Oita, Nagasaki, Kumamoto</td>
</tr>
</tbody>
</table>

The annual maximum snow depth ratio in 2016 was 82% relative to the 1981 – 2010 average for the Sea of Japan side of northern Japan, 96% for the same side of eastern Japan, and 153% for the same side of western Japan (Figure 2.2-3). The annual maximum snow depth reached a local peak in the early 1980s followed by a sharp decline until around the early 1990s. The decline was particularly striking on the Sea of Japan side of eastern and western Japan.

On a longer time scale, the annual maximum snow depth ratio from 1962 onward on the Sea of Japan side of eastern Japan is virtually certain to have decreased at rates of about 12.3% per decade (statistically significant at a confidence level of 99%), and that on the Sea of Japan side of western Japan is extremely likely to have decreased at rates of about 14.6% per decade (statistically significant at a confidence level of 95%). The annual maximum snow depth ratio on the Sea of Japan side of northern Japan shows no discernible trend.
2.2.4 Long-term trends of extreme precipitation events in Japan

This section describes long-term trends in frequencies of extremely wet/dry months and heavy daily precipitation events in Japan based on analysis of precipitation data from 51 observation stations.

Figure 2.2-3 Annual maximum snow depth ratio from 1962 to 2016 on the Sea of Japan side for northern Japan (top left), eastern Japan (top right) and western Japan (bottom). Annual averages are presented as ratios against the baseline (the 1981 – 2010 average).

The bars indicate the snow depth ratio for each year. The blue line indicates the five-year running mean, and the red line indicates the long-term linear trend.
(Chapter 2 Climate Change)

(1) Extremely wet/dry months

It is virtually certain that the frequency of extremely dry months increased during the period from 1901 to 2016 (statistically significant at a confidence level of 99%) (Figure 2.2-4 left). There has been no discernible trend in the frequency of extremely wet months (Figure 2.2-4 right).

![Figure 2.2-4  Annual number of extremely wet/dry months](image)

The graphs show the annual number of occurrences of the first-to-fourth heaviest/lightest precipitation values for each month during the period from 1901 to 2016. The green bars indicate annual occurrences of extremely heavy/light monthly precipitation divided by the total number of monthly observation data sets available for the year (i.e., the average occurrence per station). The blue line indicates the five-year running mean, and the straight red line indicates the long-term linear trend.

(2) Annual number of days with precipitation of ≥ 100 mm, ≥ 200 mm and ≥ 1.0 mm

The annual number of days with precipitation of ≥ 100 mm is virtually certain to have increased (statistically significant at a confidence level of 99%) and that with precipitation of ≥ 200 mm is extremely likely to have increased (statistically significant at a confidence level of 95%) during the period from 1901 to 2016 (Figure 2.2-5). The annual number of days with precipitation of ≥ 1.0 mm (Figure 2.2-6) is virtually certain to have decreased over the same period (statistically significant at a confidence level of 99%). These results suggest decrease in the annual number of wet days including light precipitation and in contrast, an increase in extremely wet days.

---

17 Here, judgment of extremely heavy/light precipitation is based on the fourth–highest/lowest monthly values on record over the 116-year period from 1901 to 2016. The frequency of occurrence of the highest/lowest to the fourth–highest/lowest values over this period is once every 29 years, which is close to JMA’s definition of extreme climate events as those occurring once every 30 years or longer (See the Glossary for terms relating to Extreme climate event).
2.2.5 Long-term trends of heavy rainfall analyzed using AMeDAS data

JMA operationally observes precipitation at about 1,300 unmanned regional meteorological observation stations all over Japan (collectively known as the Automated Meteorological Data Acquisition System, or AMeDAS). Observation was started in the latter part of the 1970s at many points, and observation data covering the 41-year period through to 2016 are available. Although the period covered by AMeDAS observation records is shorter than that of Local Meteorological Observatories or Weather Stations (which have observation records for the past 100 years or so), there are around eight times as many AMeDAS stations as Local Meteorological Observatories and Weather Stations combined. Hence, AMeDAS is better equipped to capture heavy precipitation events that take place on a limited spatial scale.

Here, trends in annual number of events with extreme precipitation of ≥ 50 mm/80 mm per hour (every-hour-on-the-hour observations) (Figure 2.2-7) and ≥ 200 mm/400 mm per day (Figure 2.2-8) are described based on AMeDAS observation data. It is virtually certain that the annual numbers of events with precipitation of ≥ 50 mm per hour and ≥ 80 mm per hour have increased (statistically significant at a confidence level of 99%). The annual number of days with precipitation of ≥ 200 mm shows no statistically significant trend, while the corresponding figure for days with precipitation of ≥ 400 mm is very likely to have increased (statistically significant at a confidence level of 90%).

18 The number of AMeDAS stations was about 800 in 1976, and had gradually increased to about 1,300 by 2016. To account for these numerical differences, the annual number of precipitation events needs to be converted to a per-1,000-station basis. Data from wireless robot precipitation observation stations previously deployed in mountainous areas are also excluded.
(Chapter 2 Climate Change)

As the annual number of extreme precipitation events is subject to large annual variations and the period covered by observation records is still relatively short, the addition of future observations to the data series is expected to increase the reliability of statistical trend detection.

Figure 2.2-7 Annual number of events with precipitation of ≥ 50 mm and ≥ 80 mm per hour (per 1,000 AMeDAS stations)
The graphs show the annual number of events per 1,000 AMeDAS stations, with the green bars indicating the values for each year during the period from 1976 to 2016. The blue line indicates the five-year running mean, and the straight red line indicates the long-term linear trend.

Figure 2.2-8 Annual number of days with precipitation of ≥ 200 mm and ≥ 400 mm (per 1,000 AMeDAS stations)
The graphs show the annual number of days per 1,000 AMeDAS stations, with the green bars indicating the values for each year during the period from 1976 to 2016. The blue line indicates the five-year running mean, and the straight red line indicates the long-term linear trend.
2.3 Changes in the phenology of cherry blossoms and acer leaves in Japan

- It is virtually certain that cherry blossoms have been flowering earlier.
- It is virtually certain that acer leaves have been changing color later.

JMA implements phenological observation to research the impact of meteorological condition on plants and animals, and eventually to monitor the progress of seasons as well as geographical variations and long-term changes in relation to the climate. Observation covers the first/full flowering and leaf color change of several plants and the first reported appearance/song of insects, birds and animals.

As part of its phenological monitoring, JMA observes cherry blossoms at 58 stations and acer leaves at 51 stations. Figure 2.3-1 shows interannual changes in the first reported dates of cherry blossom flowering and acer leaf color change between 1953 and 2016. The former exhibits a long-term advancing trend at a rate of 1.0 days per decade, while the latter shows a delaying trend at a rate of 2.9 days per decade (99% level of confidence for both cases). Table 2.3-1 compares climatological normals (based on 30-year averages) of the first reported date of cherry blossom flowering between 1961 – 1990 and 1981 – 2010 at stations in major Japanese cities. These phenomena are closely related to the surface mean temperature in the period before the event, and long-term warming is considered to be a major factor behind the trends observed.

Figure 2.3-1 First reported dates of cherry blossom flowering (left) and acer leaf color change (right)

The black lines show annual anomalies of the first reported date averaged over all observation stations nationwide based on the normals for 1981 – 2010, and the blue lines indicate five-year running means. The red lines show the linear trend (cherry blossoms: −1.0 days per decade; acer leaves: +2.9 days per decade).

Table 2.3-1 Comparison of first reported dates of cherry blossom flowering

<table>
<thead>
<tr>
<th>Station</th>
<th>1961-1990 average</th>
<th>1981-2010 average</th>
<th>Difference (days)</th>
<th>Station</th>
<th>1961-1990 average</th>
<th>1981-2010 average</th>
<th>Difference (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kushiro</td>
<td>May 19</td>
<td>May 17</td>
<td>-2</td>
<td>Osaka</td>
<td>Apr 1</td>
<td>Mar 28</td>
<td>-4</td>
</tr>
<tr>
<td>Sapporo</td>
<td>May 5</td>
<td>May 3</td>
<td>-2</td>
<td>Hiroshima</td>
<td>Mar 31</td>
<td>Mar 27</td>
<td>-4</td>
</tr>
<tr>
<td>Aomori</td>
<td>Apr 27</td>
<td>Apr 24</td>
<td>-3</td>
<td>Takamatsu</td>
<td>Mar 31</td>
<td>Mar 28</td>
<td>-3</td>
</tr>
<tr>
<td>Sendai</td>
<td>Apr 14</td>
<td>Apr 11</td>
<td>-3</td>
<td>Fukuoka</td>
<td>Mar 28</td>
<td>Mar 23</td>
<td>-5</td>
</tr>
<tr>
<td>Niigata</td>
<td>Apr 13</td>
<td>Apr 9</td>
<td>-4</td>
<td>Kagoshima</td>
<td>Mar 27</td>
<td>Mar 26</td>
<td>-1</td>
</tr>
<tr>
<td>Tokyo</td>
<td>Mar 29</td>
<td>Mar 26</td>
<td>-3</td>
<td>Naha</td>
<td>Jan 16</td>
<td>Jan 18</td>
<td>+2</td>
</tr>
<tr>
<td>Nagoya</td>
<td>Mar 30</td>
<td>Mar 26</td>
<td>-4</td>
<td>Ishigakijima</td>
<td>Jan 15</td>
<td>Jan 16</td>
<td>+1</td>
</tr>
</tbody>
</table>
2.4 Tropical cyclones

- A total of 26 tropical cyclones (TCs) with maximum wind speeds of 17.2 m/s or higher formed in 2016, which was near normal.
- The numbers of formations show no significant long-term trend.

In 2016, 26 tropical cyclones (TCs) with maximum wind speeds of 17.2 m/s or higher formed over the western North Pacific (Figure 2.4-1), which was near the normal (i.e., the 1981–2010 average) of 25.6. The numbers of formations show no discernible long-term trend during the analysis period from 1951 to 2016, but have often been lower since the latter half of the 1990s than in previous years.

Figure 2.4-2 shows the numbers and rates of tropical cyclones with maximum wind speeds of 33 m/s or higher to those with maximum wind speeds of 17.2 m/s or higher from 1977 (the year in which the collection of complete data on maximum wind speeds near TC centers began). The numbers of tropical cyclones with maximum wind speeds of 33 m/s or higher show no discernible trend.

![Figure 2.4-1](image1.png)  Time-series of the numbers of tropical cyclones with maximum winds of 17.2 m/s or higher forming in the western North Pacific.

The thin and thick lines represent annual and five-year running means, respectively.

![Figure 2.4-2](image2.png)  Time-series of the numbers of strong tropical cyclones (blue) and rates of the strong tropical cyclones to the total tropical cyclones (red) forming in the western North Pacific. The strong tropical cyclones are those with maximum winds of 33 m/s or higher.

The thin and thick lines represent annual and five-year running means, respectively.
2.5 Sea surface temperature

- The annual mean global average sea surface temperature (SST) in 2016 was 0.33°C above the 1981 – 2010 average, which was the highest since 1891.
- The global average SST has risen at a rate of about +0.53°C per century.
- Annual average SSTs around Japan have risen by +1.09°C per century.

2.5.1 Global sea surface temperature

The annual mean global average SST in 2016 was 0.33°C above the 1981 – 2010 average. This was higher than the previous highest value of +0.30°C observed in 2015, and was the highest since 1891. The linear trend from 1891 to 2016 shows an increase of +0.53°C per century (Figure 2.5-1). Both global average SST and global average surface temperature (Section 2.1) are affected by natural climate variability on interannual to interdecadal time scales as well as by global warming. In particular, the global average SST shows an association with the NINO.3 SST anomaly with a time lag of several months (Trenberth et al., 2002). Accordingly, 2016’s record-high temperatures may have been caused by the El Niño event that persisted from summer 2014 to spring 2016 (Section 1.3). Although magnitudes of the long-term SST trend vary by area, SSTs are extremely likely to have increased in many parts of the world’s oceans (Figure 2.5-2).

On a multi-year time scale, the global average SST showed a warming trend from the middle of the 1970s to around 2000 and remained at the same level to the early 2010s (blue line in Figure 2.5-1). This is partly because internal decadal to multi-decadal variations in the climate system overlap with the rising trends. It is important to estimate the contribution of these internal variations in order to properly understand global warming. In the next section, the Pacific Decadal Oscillation (PDO) is presented as a typical example of decadal variability observed in SSTs.

Figure 2.5-1  Time-series representation of global average sea surface temperature anomalies from 1891 to 2016

The black, blue and red lines indicate annual anomalies, the five-year running mean and the long-term linear trend, respectively. Anomalies are deviations from the 1981 – 2010 average.

Figure 2.5-2  Linear trend of annual mean sea surface temperature during the period from 1891 to 2016 (°C per century)

Plus signs indicate statistically significant trends with a confidence level of 95%.

19 The results of analysis regarding tendencies of SSTs worldwide and around Japan are published on JMA’s website.
http://www.data.jma.go.jp/gmd/kaiyou/english/long_term_sst_global/glb_warm_e.html
2.5.2 Sea surface temperature (around Japan)

Figure 2.5-3 shows increase rates of area-averaged annual mean SSTs for 13 areas around Japan. The average SST of all areas around Japan has risen by +1.09°C per century, which is higher than the corresponding value for the North Pacific (+0.50°C per century).

It is virtually certain (statistically significant at a confidence level of 99%) that SSTs have risen by between +0.75 and +1.70°C per century in the Yellow Sea, the East China Sea, the sea around the Sakishima Islands, central and southwestern parts of the Sea of Japan, the southern part of the sea off Kanto, the sea off Shikoku and Tokai, the sea off Kushiro, and the sea east of Okinawa (areas I-VI, VII, X, XII, and XIII). It is extremely likely (statistically significant at a confidence level of 95%) that SSTs in the sea off Sanriku, and the eastern part of the sea off Kanto (areas VIII and IX) have risen by +0.68°C and +0.70°C per century, respectively. SSTs in the northeastern part of the Sea of Japan (Area XI) exhibit no statistical long-term trend.

<table>
<thead>
<tr>
<th>Area number</th>
<th>Area name</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Yellow Sea</td>
</tr>
<tr>
<td>II</td>
<td>Northern part of the East China Sea</td>
</tr>
<tr>
<td>III</td>
<td>Southern part of the East China Sea</td>
</tr>
<tr>
<td>IV</td>
<td>Sea around the Sakishima Islands</td>
</tr>
<tr>
<td>V</td>
<td>Sea off Shikoku and Tokai</td>
</tr>
<tr>
<td>VI</td>
<td>East of Okinawa</td>
</tr>
<tr>
<td>VII</td>
<td>Sea off Kushiro</td>
</tr>
<tr>
<td>VIII</td>
<td>Sea off Sanriku</td>
</tr>
<tr>
<td>IX</td>
<td>Eastern part of the sea off Kanto</td>
</tr>
<tr>
<td>X</td>
<td>Southern part of the sea off Kanto</td>
</tr>
<tr>
<td>XI</td>
<td>Northeastern part of the Sea of Japan</td>
</tr>
<tr>
<td>XII</td>
<td>Central part of the Sea of Japan</td>
</tr>
<tr>
<td>XIII</td>
<td>Southwestern part of the Sea of Japan</td>
</tr>
</tbody>
</table>

Figure 2.5-3  Increase rates of area-averaged annual mean SSTs around Japan from 1900 to 2016 (°C per century)
Areas with no symbol and those marked with [*] have statistical significant trend at confidence levels of 99% and 95%, respectively. Areas marked with [#] are those where no discernible trend is seen due to large SST variability factors such as decadal oscillation.
2.6 El Niño/La Niña and PDO (Pacific Decadal Oscillation)

- An El Niño event that began in summer 2014 passed on its mature stage in November–December 2015 and ended in spring 2016.
- Although negative PDO index values were generally observed from around 2000 to the early 2010s, the positive annual mean values have been recorded consecutively since 2014.

2.6.1 El Niño/La Niña

An El Niño event is a phenomenon in which sea surface temperatures (SSTs) are higher than normal across a wide area from the center of the equatorial Pacific to the region off the coast of Peru for a period of between half a year and 1.5 years. In contrast, a La Niña event is a phenomenon in which SSTs are lower than normal in the same area. Both occur once every few years, causing changes in global atmospheric conditions and abnormal weather conditions worldwide. In Japan, cooler summers and warmer winters tend to appear during El Niño events, while hotter summers and colder winters tend to appear during La Niña events. El Niño/La Niña events also tend to cause SST changes in the tropical Indian Ocean with a delay of approximately three months from changes in the El Niño monitoring region. Such changes in the tropical Indian Ocean are considered to cause abnormal weather conditions worldwide.

Figure 2.6-1 shows a time-series representation of SST deviations from the climatological mean based on a sliding 30-year period for the El Niño monitoring region (5°N – 5°S, 150°W – 90°W) and the tropical Indian Ocean (20°N – 20°S, 40°E – 100°E) since 2006. An El Niño event that began in summer 2014 passed on its mature stage in November–December 2015 and ended in spring 2016. In the tropical Indian Ocean, the five-month running mean of SST deviations (from the climatological mean based on a sliding 30-year period) peaked in February–March 2016 and turned negative in summer 2016. Influences of this El Niño event and high SSTs in the tropical Indian Ocean on the global climate are described in Topics I.

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20 See the Glossary for terms relating to El Niño phenomena. Monthly diagnosis reports, ENSO monitoring products, ENSO indices and El Niño outlooks are published on JMA’s website.

21 The PDO index time series is published on JMA’s website.
2.6.2 Pacific Decadal Oscillation

SST variability is also observed on time scales ranging from one to several decades in addition to El Niño/La Niña events, whose time scale is several years, and long-term trends associated with global warming. Among these, the atmosphere and oceans tend to co-vary with a period of more than ten years in the North Pacific in a phenomenon known as the Pacific Decadal Oscillation (PDO). When SSTs are lower than their normals in the central part of the North Pacific, those in its eastern part and in the equatorial Pacific are both likely to be higher than their normals. This seesaw pattern changes slowly, and appears repeatedly with a period of more than ten years. The PDO index, which is defined by the SST anomaly pattern in the North Pacific, is used as a measure of phase and strength of the oscillation. Both the PDO index and SST anomaly patterns associated with PDO include relatively short-timescale variabilities such as El Niño/La Niña events in addition to decadal to multi-decadal components.

When the PDO index is positive (negative), SSTs in the central part of the North Pacific are likely to be lower (higher) than their normals (Figure 2.6-2), and sea level pressures (SLPs) in the high latitudes of the North Pacific are likely to be lower (higher) than their normals. This indicates that the Aleutian Low is stronger (weaker) than its normal in winter and spring (Figure 2.6-3). These atmospheric variations affect meteorological conditions mainly in North America. When the PDO index is positive, winter temperatures tend to be high in the northwestern part of North America and the northern part of South America, and low in the southeastern part of the USA and in parts of China (Mantua and Hare, 2002).

The PDO index was generally positive from the late 1920s to the early 1940s and from the late 1970s to around 2000, and generally negative from the late 1940s to 1970s and from around 2000 to the early 2010s. The annual mean PDO index value has been positive consecutively since 2014 and was +1.3 in 2016 (Figure 2.6-4).
Figure 2.6-2 Typical SST anomaly patterns in the positive phase of the PDO

Figure 2.6-3 Typical SLP anomaly patterns in the positive phase of the PDO

Figure 2.6-4 Time-series of the PDO index

The red line represents annual mean values for the PDO index, the blue line represents five-year running mean values, and the gray bars represent monthly values.
2.7 Global upper ocean heat content

An increase in globally integrated upper ocean heat content was observed from 1950 to 2016 with a linear trend of \(2.22 \times 10^{22}\) J per decade.

Oceans have a significant impact on the global climate because they cover about 70% of the earth’s surface and have high heat capacity. According to the Intergovernmental Panel on Climate Change Fifth Assessment report (IPCC, 2013), more than 60% of the net energy increase in the climate system from 1971 to 2010 is stored in the upper ocean \((0 – 700\ m)\), and about 30% is stored below 700 m. Oceanic warming results in sea level rises due to thermal expansion.

It is virtually certain that globally integrated upper ocean \((0 – 700\ m)\) heat content (OHC) rose between 1950 and 2016 at a rate of \(2.22 \times 10^{22}\) J per decade as a long-term trend with interannual variations (statistically significant at a confidence level of 99%) (Figure 2.7-1). This OHC increasing trend corresponds to a rise of 0.023°C per decade in the globally averaged upper ocean \((0 – 700\ m)\) temperature. OHC exhibited marked increases from the mid-1990s to the early 2000s and slight increases for the next several years, as seen with the global mean surface temperature and the sea surface temperature. Since the mid-2000s OHC has increased again significantly. These long-term trends can be attributed to global warming caused by increased concentrations of anthropogenic greenhouse gases such as CO₂ as well as natural variability.

Figure 2.7-1  Time-series representation of the globally integrated upper ocean \((0 – 700\ m)\) heat content anomaly

The 1981 – 2010 average is referenced as the normal.

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22 The results of ocean heat content analysis are published on JMA’s website. http://www.data.jma.go.jp/gmd/kaiyou/english/ohc/ohc_global_en.html
2.8 Sea levels around Japan

- A trend of sea level rise has been seen in Japanese coastal areas since the 1980s.
- No clear trend of sea level rise was seen in Japanese coastal areas for the period from 1906 to 2016.

The IPCC Fifth Assessment Report 2013 (AR5) concluded that the global mean sea level had risen due mainly to 1) oceanic thermal expansion, 2) changes in mountain glaciers, the Greenland ice sheet and the Antarctic ice sheet, and 3) changes in land water storage. The report also said it is very likely that the mean rate of global average sea level rise was 1.7 [1.5 to 1.9] mm/year between 1901 and 2010, 2.0 [1.7 to 2.3] mm/year between 1971 and 2010, and 3.2 [2.8 to 3.6] mm/year between 1993 and 2010, where the values in square brackets show the 90% uncertainty range.

Sea levels in Japanese coastal areas exhibited no significant rise from 1906 to 2016 (Figure 2.8-1), but have shown a rising trend since the 1980s. Recent rates of rise around the country have been 1.1 [0.6 to 1.6] mm/year from 1971 to 2010 and 2.8 [1.3 to 4.3] mm/year from 1993 to 2010. These are comparable to the global average figures provided in AR5.

In Japanese coastal areas, variations with 10- to 20-year periods were between 1906 and 2016, with the maximum sea level appearing around 1950. The major factor behind sea level variations with 10- to 20-year periods is the variability of atmospheric circulation over the North Pacific. Westerlies in the mid-latitudes of the Northern Hemisphere are strengthened in boreal winter, and the consequent decadal variations in turn cause sea level variations in the central North Pacific. These propagate westward due to the earth’s rotation, causing sea level rise around Japan.

The extent to which global warming has contributed to sea level change around Japan remains unclear due to the involvement of various other factors such as variations with 10- to 20-year periods as mentioned above. Continuous monitoring is needed to clarify the long-term trend of sea level rise caused by global warming.

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23 Sea levels around Japan are published on the JMA’s website. http://www.data.jma.go.jp/gmd/kaiyou/english/si_trend/sea_level_around_japan.html
Figure 2.8-1  Time-series representation of annual mean sea levels (1906 – 2016) and locations of tide gauge stations

Tide gauge stations assessed as being affected to a lesser extent by crustal movement are selected. The four stations shown on the map on the left are used for the period from 1906 to 1959, and the sixteen shown on the right are used for the period since 1960. From 1906 to 1959, a time-series representation of mean annual mean sea level anomalies for the selected stations is shown. For the period since 1960, cluster analysis was first applied to sea level observation data for the selected stations along the Japanese coast. The nation’s islands were then divided into four regions based on sea level variation characteristics, annual mean sea level anomalies were averaged for each of the regions, and the variations were plotted in the figure. The four regions are I: from Hokkaido to Tohoku district; II: from Kanto to Tokai district; III: from the Pacific coast of Kinki to that of Kyushu district; and IV: from Hokuriku to East China Sea coast of Kyushu district. Sea level variations are plotted on the chart as a time-series representation of annual mean sea level anomalies for each year, obtained using the 1981 to 2010 average as the normal. The solid blue line represents the five-year running mean of annual sea level anomalies averaged among the four stations shown in the lower left map, while the solid red line represents that averaged among the four divided regions in the lower right map. The dashed blue line represents the value averaged among the four stations shown in the lower left map for the same period shown by the solid red line (after 1960) for reference. The coefficient of correlation between the solid red line and the dashed blue line from 1962 to 2014 is as high as 0.98. Accordingly, the extent to which changing the tide gauge stations used in the monitoring affects the analysis of variance of sea level anomalies can be regarded as small. Among the tide gauge stations, those at Oshoro, Kashiwazaki, Wajima and Hosojima belong to the Geospatial Information Authority of Japan. Sea level data for the Tokyo station are available from 1968 onward. Sea level data for the period from 2011 to 2016 from Hakodate, Fukaura, Kashiwazaki, Tokyo and Hachinohe were not used due to possible influences from the 2011 off the Pacific coast of Tohoku Earthquake.
2.9 Sea ice

- The sea ice extent in the Arctic Ocean shows a decreasing trend. In 2016, the annual minimum sea ice extent in the Arctic Ocean was $4.10 \times 10^6$ km$^2$, and the annual maximum was $14.74 \times 10^6$ km$^2$, which were both the second-smallest values recorded since 1979.
- The sea ice extent in the Antarctic Ocean shows an increasing trend. In 2016, however, the annual mean sea ice extent in the Antarctic Ocean was $11.61 \times 10^6$ km$^2$, which was the fourth-smallest value recorded since 1979.
- The maximum sea ice extent in the Sea of Okhotsk shows a decreasing trend of $0.067 \times 10^6$ km$^2$ per decade.

### 2.9.1 Sea ice in Arctic and Antarctic areas (Figure 2.9-1)

Sea ice is formed when sea water in the Arctic and Antarctic freezes. As the albedo (reflection coefficient) of sea ice is greater than that of the ocean surface, sea ice extent reductions caused by global warming result in more solar energy absorption at the surface, which in turn accelerates global warming. Sea ice also affects deep-ocean circulation because the expelled salt as it forms increases the salinity (and therefore the density) of the water below it causing the water to sink.

It is virtually certain that there has been a long-term trend of decrease in sea ice extent in the Arctic Ocean since 1979 when continuous monitoring of sea ice using satellite sensors with similar properties started (statistically significant at a confidence level of 99%). In particular, the reduction in the annual minimum extent is notable. The rate of decrease in the annual

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24 Information on sea ice in the Arctic/Antarctic, and in the Sea of Okhotsk are published on JMA’s website.

http://www.data.jma.go.jp/gmd/kaiyou/english/seaice_global/series_global_e.html (Arctic/Antarctic)

http://www.data.jma.go.jp/gmd/kaiyou/english/seaice_okhotsk/series_okhotsk_e.html (Sea of Okhotsk)
minimum up to 2016 was $0.092 \times 10^6$ km$^2$ per year and the annual minimum was $4.10 \times 10^6$ km$^2$, which was the second-lowest record since 1979. The annual maximum sea ice extent in the Arctic Ocean was $14.74 \times 10^6$ km$^2$, which was also the second-lowest record since 1979. Meanwhile, it is virtually certain that there has been an increase at a rate of $0.025 \times 10^6$ km$^2$ per year in the annual mean sea ice extent in the Antarctic Ocean (statistically significant at the confidence level of 99%). However, the value for 2016 was $11.61 \times 10^6$ km$^2$, which was the fourth-lowest record since 1979.

2.9.2 *Sea ice in the Sea of Okhotsk (Figure 2.9-2)*

The Sea of Okhotsk is the southernmost sea in the Northern Hemisphere where sea ice is observed across a wide area. The variation of the sea ice in the Sea of Okhotsk has effect on climate in coastal area facing the Sea of Okhotsk in Hokkaido and water quality of Oyashio.

The maximum$^{25}$ sea ice extent in the Sea of Okhotsk shows large interannual variations. However, it is virtually certain that it exhibited a long-term trend of decrease for the period from 1971 to 2016 (statistically significant at the confidence level of 99%). The maximum extent has decreased by $0.067 \times 10^6$ km$^2$ per decade (corresponding to 4.3% of the Sea of Okhotsk’s total area).

![Figure 2.9-2 Time-series representations of maximum sea ice extent for the Sea of Okhotsk from 1971 to 2016](image)

Straight line indicates the linear trend.

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$^{25}$ The maximum sea ice extent: It shows sea ice extent that sea ice was the most expanding of every five days in the course of the year.
2.10 Snow cover in the Northern Hemisphere

- A decreasing trend is observed in the interannual variability of the total snow cover extent in the Northern Hemisphere for May, June and the period from September to December.
- In winter 2015/2016, there were fewer days of snow cover than normal in many parts of the Northern Hemisphere.

The albedo of snow-covered ground (i.e., the ratio of solar radiation reflected by the surface) is higher than that of snow-free ground. The variability of snow cover has an impact on the earth’s surface energy budget and radiation balance, and therefore on the climate. In addition, snow absorbs heat from its surroundings and melts, thereby providing soil moisture and related effects on the climate system. The variability of atmospheric circulation and oceanographic conditions affects the amount of snow cover, which exhibits a close and mutual association with climatic conditions. JMA monitors snow-cover variations in the Northern Hemisphere using analysis data derived from observations conducted by the Special Sensor Microwave/Imager (SSM/I) and the Special Sensor Microwave Imager Sounder (SSMIS) on board the Defense Meteorological Satellite Program (DMSP) polar-orbiting satellites of the USA based on an algorithm developed by JMA.

In the Northern Hemisphere (north of 30°N), there was a decreasing trend (statistically significant at a confidence level of 95%) in the interannual variability of the total snow cover extent over the 29-year period from 1988 to 2016 for May, June and the period from September to December (Figure 2.10-1 bottom-left), while no trend is seen for the period from January to April (Figure 2.10-1 top-left). In winter (December – February) 2015/2016, there were fewer days of snow cover than normal in many parts of the Northern Hemisphere. In February, significantly fewer-than-normal snow cover days were observed in western Eurasia (Figure 2.10-1, top right), and the snow cover extent in the Northern Hemisphere was the smallest since 1988. In November 2016, there were more days of snow cover than normal around Central Asia and in northeastern China, and fewer in western China and North America (Figure 2.10-1, bottom right).
Figure 2.10-1 Interannual variations in the total area of monthly snow cover (km²) in the Northern Hemisphere (north of 30°N) over the period from 1988 to 2016 for February and November (left), and anomalies in the number of days with snow cover for February 2016 and November 2016 (right).

Left: the blue lines indicate the total snow cover area for each year, and the black lines show linear trends (statistically significant at a confidence level of 95%).

Right: statistics on the number of days with snow cover are derived using data from the Special Sensor Microwave Imager (SSM/I) and the Special Sensor Microwave Imager Sounder (SSMIS) on board the US Defense Meteorological Satellite Program (DMSP) satellites based on an algorithm developed by the Japan Meteorological Agency. The base period for the normal is 1989 – 2010.