CLIMATE CHANGE MONITORING REPORT
2009

July 2010
JAPAN METEOROLOGICAL AGENCY
Cover: Three-dimensional representations of monthly variations in zonally averaged atmospheric CO$_2$ distribution (concentrations (top) and growth rates (bottom)). This analysis was performed using data archived by the WDCGG.
Preface

The years from 2008 to 2012 represent the first commitment period of the quantified economy-wide emission target under the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC), and 2010 marks the third year of this period.

In addition, intense international negotiations are under way on the post-Kyoto framework, and international momentums to promote mitigation actions are being accelerated. At the 15th Session of the Conference of the Parties to the UNFCCC (COP15) in December 2009, Japan’s government declared that the country would reduce its greenhouse gas emissions by 25 percent compared with 1990 levels by 2020, which is premised on the establishment of a fair and effective international framework in which all major economies participate and on agreement by those economies on ambitious targets.

At the World Climate Conference-3 (WCC-3) held from 31 August to 4 September, 2009, the formation of the Global Framework for Climate Services (GFCS) was decided upon with the aim of using climate information to make adaptation plans for climate change. The heavy burdens placed on the social economy by severe weather and climate phenomena such as heavy precipitation, drought, heat waves and cold waves give rise to an increasing need for climate information, and expectations of improvements to easy-to-use climate information have grown worldwide.

Since 1996, the Japan Meteorological Agency (JMA) has published a series of assessments under the title of the Climate Change Monitoring Report. These publications highlight the outcomes of JMA’s activities, including the monitoring and analysis of greenhouse gases and the ozone layer, thereby providing up-to-date information on the climatic conditions of the world and Japan.

It is my hope that readers of this report will find it useful in gaining a better understanding of the latest status of the climate toward further protection of the global environment. I would like to take this opportunity to convey my sincere appreciation to the members of JMA’s Advisory Group of the Council for Climate Issues under the chairmanship of Dr. Hiroki Kondo for their pertinent comments and guidance in our work on this report.

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Part I  Climate

1  Global Climate

1.1  Global climate

1.1.1  Major climate anomalies

Figures 1.1.1 and 1.1.2 show anomalies in the annual mean temperature (normalized by its standard deviation) and annual total precipitation amount ratios for 2009 respectively. The climatological normal values for temperature and precipitation amounts are calculated using statistics from the period 1971 – 2000. Figures 1.1.3 and 1.1.4 show frequencies of extremely high/low temperatures and heavy/light precipitation amounts respectively. Extremely high/low temperatures and heavy/light precipitation amounts are defined as values that are observed only once every 30 years or longer.

Annual mean temperatures were above normal in most areas of the world except in central Siberia and from Canada to the USA (Figure 1.1.1). Extremely high temperatures were frequently observed around low latitudes from 30°S to 30°N (Figure 1.1.3), while extremely low temperatures were observed around the central USA in October and December, around China in November and from western Siberia to eastern China in December.

Annual precipitation amounts were above normal in eastern Siberia, from the Philippines to Indonesia and from Europe to northern Africa, while they were below normal over the Arabian Peninsula, in southern South America and from central to southern Australia (Figure 1.1.2). Extremely heavy precipitation amounts were frequently observed in northern Europe, while extremely light precipitation amounts were frequently observed in northern Argentina (Figure 1.1.4).


1.1.2  Extreme climate events

Major extreme climate events and weather-related disasters across the world for 2009 are listed below, and are also indicated schematically in Figure 1.1.5.

(1) Low temperatures from western Siberia to eastern China (December)
(2) Low temperatures around China (November)
(3) Heavy precipitation amounts from eastern Mongolia to Northern Japan (December)
(4) High temperatures from China to the Middle East (February – October)
(5) Typhoons and torrential rains in the Philippines (May, September – October)
(6) High temperatures from Micronesia to Indonesia (April to December)
(7) Torrential rains in southern India (September – October)
(8) Heavy precipitation amounts in northern Europe (July)
(9) Heavy precipitation amounts from the Aral Sea to northern Africa (September)
(10) Torrential rains in southern Africa (March)
(11) High temperatures around Madagascar (January – February, May – December)
(12) Low temperatures around the central USA (October, December)
(13) High temperatures from Central America to northern South America (May – December)
(14) Light precipitation amounts around northern Argentina (January, March – April)
(15) Heat waves and bushfires in southeastern Australia (January – February)
Figure 1.1.1  Annual mean temperature anomalies for 2009

Categories are defined by the annual mean temperature anomaly against the normal divided by its standard deviation and averaged in 5° × 5° grid boxes. The thresholds of each category are −1.28, −0.44, 0, +0.44 and +1.28. Land areas without graphics represent regions for which the sample size of observation data is insufficient or normal data are unavailable.

Figure 1.1.2  Annual total precipitation amount ratios for 2009

Categories are defined by the annual precipitation ratio to the normal, averaged in 5° × 5° grid boxes. The thresholds of each category are 70%, 100% and 120%. Land areas without graphics represent regions for which the sample size of observation data is insufficient or normal data are unavailable.
Figure 1.1.3  Frequencies of extremely high/low temperatures for 2009
The frequencies of extremely high/low temperatures are marked with upper/lower red/blue semicircles. The size of the semicircle represents the ratio of extremely high/low temperature based on monthly observation for the year in each $5^\circ \times 5^\circ$ grid box. Since the frequency of extremely high/low temperatures is expected to be about 3% on average, occurrence is deemed to be above normal in cases of 10 – 20% or more. Land areas without graphics represent regions for which the sample size of observation data is insufficient or normal data are unavailable.

Figure 1.1.4  Frequencies of extremely heavy/light precipitation for 2009
The frequencies of extremely heavy/light precipitation are marked with upper/lower green/orange semicircles. The size of the semicircle represents the ratio of extremely heavy/light precipitation based on monthly observation for the year in each $5^\circ \times 5^\circ$ grid box. Since the frequency of extremely heavy/light precipitation is expected to be about 3% on average, occurrence is deemed to be above normal in cases of 10 – 20% or more. Land areas without graphics represent regions for which the sample size of observation data is insufficient or normal data are unavailable.
1.2 Global surface temperature and precipitation

The annual anomaly of the global average surface temperature in 2009 (i.e. the average of the near-surface air temperature over land and the SST) was 0.31°C above normal (based on the 1971 – 2000 average), and tied with 2002, 2003 and 2006 as the third warmest on record since 1891 (Figure 1.1.6).

Global average temperatures have varied along different time scales ranging from a few years to several decades. On a longer time scale, global average surface temperatures have been rising at a rate of about 0.68°C per century since 1891 (the earliest date for which instrumental temperature records are available). This long-term trend can be attributed to global warming caused by an increase in greenhouse gases such as CO₂. According to the IPCC Fourth Assessment Report (AR4), most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in concentrations of anthropogenic greenhouse gases.

The surface temperature over the Northern Hemisphere in 2009 was the seventh warmest since 1891, and that over the Southern Hemisphere was the second warmest. Surface temperatures over the Northern and Southern Hemispheres have been rising at a rate of about 0.70°C and 0.66°C per century respectively.

The ratio of global annual precipitation (for land areas only) to the normal in 2009 (i.e. the 1971 – 2000 average) was 100%. Although annual precipitation (for land areas only) over the Southern Hemisphere has varied periodically since 1880, a positive trend has been observed. On the other hand, the Northern Hemisphere has experienced no significant trend, and received large amounts of rainfall in the 1880s, around 1930, in the 1950s and in the 1990s (Figure 1.1.7). The trend of global average precipitation is also unclear because of the sparsity of observation sites in the Southern Hemisphere compared to those in the Northern Hemisphere.

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1 According to AR4, the 100-year linear trend of global average temperature is 0.74°C for 1906 to 2005. It is considered that the values in AR4 and those in this report show no remarkable difference, although they do not correspond exactly because of differences in calculation methods and the statistical period examined.
Figure 1.1.6  Annual anomalies in surface temperature (i.e. the average of the near-surface air temperature over land and the SST) from 1891 to 2009 globally (top), for the Northern Hemisphere (middle) and for the Southern Hemisphere (bottom). Anomalies are deviations from the normal (i.e. the 1971 – 2000 average). The bars indicate anomalies in surface temperature for each year. The blue lines indicate five-year running means, and the red lines indicate long-term linear trends.
Figure 1.1.7  Annual precipitation ratios (land only) from 1880 to 2009 globally (top), for the Northern Hemisphere (middle) and for the Southern Hemisphere (bottom). The bars indicate the ratios of annual precipitation to the normal (i.e. the 1971 – 2000 average). The green lines indicate five-year running means.
2 Climate of Japan

2.1 Japan’s climate in 2009

Since the winter monsoon was much weaker than usual, seasonal mean temperatures were above normal nationwide, and snowfall amounts were significantly below normal on the Sea of Japan side. In April, May and June on the Sea of Japan side of eastern Japan and in western Japan, precipitation amounts were significantly below normal due to cover by a traveling high-pressure system and the limited influence of cyclones and fronts. Since cloudy and rainy weather was dominant in July, August and November, sunshine durations were significantly below normal across mainland Japan. In July and August, cyclones, fronts and typhoons brought localized heavy rain to many parts of the country.

The number of tropical cyclones (TCs) with maximum wind speeds of 17.2 m/s or higher forming in the western North Pacific in 2009 was 22, which was below normal (normal: 26.7, range of near-normal: 25 – 29). The number of TCs that came within 300 km of Japan's mainland and islands was 8, which was below normal (normal: 10.8). Typhoon Melor (T0918) made landfall on mainland Japan.

2.1.1 Annual climate anomalies and records (Table 1.2.1, Figure 1.2.1)

(1) Annual mean temperatures

Area-averaged annual mean temperatures were above normal nationwide. Anomalies were +0.6°C in northern and western Japan, +0.7°C in eastern Japan and +0.5°C in Okinawa/Amami.

(2) Annual precipitation amounts

Annual precipitation amounts were above normal on the Pacific side of northern Japan and below normal on the Sea of Japan side of western Japan and in Okinawa/Amami.

(3) Annual sunshine durations

Annual sunshine durations were below normal in northern Japan, eastern Japan and on the Sea of Japan side of western Japan and above normal in Okinawa/Amami.

2.1.2 Climate by season (Figure 1.2.2)

(1) Winter (December 2008 to February 2009)

Since the winter monsoon was much weaker than usual, seasonal mean temperatures were above normal nationwide. In particular, they were significantly high in northern Japan, eastern Japan and Okinawa/Amami. Snowfall amounts were also significantly below normal on the Sea of Japan side. Cyclones periodically passed near mainland Japan, and consequently precipitation amounts were above normal on the Pacific side. Anticyclones tended to cover the area around Okinawa/Amami, where seasonal sunshine durations and precipitation amounts were significantly above and below normal respectively.

(2) Spring (March to May 2009)

Seasonal mean temperatures were above normal in northern, eastern and western Japan. In
western Japan, seasonal precipitation amounts and sunshine duration amounts were significantly below and above normal respectively due to the limited influence of cyclones and fronts. In Okinawa/Amami, cloudy or rainy weather was dominant in March and April, while sunny weather dominated in May.

(3) Summer (June to August 2009)

Cloudy or rainy weather was dominant in mainland Japan during the summer. As a result, seasonal sunshine durations were below normal over northern, eastern and western Japan, and seasonal precipitation amounts were above normal in northern Japan and on the Sea of Japan side of western Japan. In the second half of July and the first half of August, cyclones, fronts and typhoons brought localized heavy rain to many parts of Japan. Seasonal temperatures were above normal in Okinawa/Amami because hot and sunny weather was dominant under the subtropical high in July and August.

(4) Autumn (September to November 2009)

Seasonal mean temperatures were near normal in northern and eastern Japan, although temperatures swung widely. In Okinawa/Amami, seasonal mean temperatures were significantly above normal due to hot weather in the first half of autumn. Monthly precipitation amounts were significantly below normal nationwide in September due to dominant anticyclones. In contrast, in November they were significantly above normal in western Japan due to the frequent passage of cyclones and fronts around the country. In October, Typhoon Melor (0918) made landfall on mainland Japan bringing heavy rainfall and strong winds.

(5) Early winter (December 2009)

In the first half of December, temperatures were above normal nationwide and heavy precipitation was brought to the Pacific side by migratory lows. In contrast, the second half of the month saw a strong cold surge bringing heavy snowfall to the Sea of Japan side and low temperatures to the whole of Japan. Monthly snowfall amounts were above normal on the Sea of Japan side of eastern Japan for the first time in four years.
Figure 1.2.1 Annual climate anomalies/ratios throughout Japan for 2009. The normal is the 1971 – 2000 average.
Table 1.2.1  Number of stations where record highs or lows were observed in 2009 for monthly, seasonal and annual values of temperature, precipitation and sunshine duration

<table>
<thead>
<tr>
<th>2009</th>
<th>Mean temperatures</th>
<th>Precipitation amounts</th>
<th>Sunshine durations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Highest</td>
<td>Lowest</td>
<td>Heaviest</td>
</tr>
<tr>
<td>January</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>February</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter (December 2008 to February 2009)</td>
<td>5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>March</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>April</td>
<td></td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>May</td>
<td>1</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Spring (March to May)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>August</td>
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<td></td>
</tr>
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<td>December</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual value</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1.2.2 Seasonal anomalies/ratios over Japan in 2009. The normal is the 1971 – 2000 average. (a) Winter (December 2008 to February 2009), (b) spring (March to May), (c) summer (June to August), (d) autumn (September to November)
2.2 Major meteorological disasters in Japan

Meteorological disasters in 2009 were characterized by serious damage resulting from the Chugoku and northern Kyushu heavy rainfall of July 2009 from 19 to 26 July and nationwide damage from gales and heavy rainfall related to October’s Typhoon MELOR (0918) – the first typhoon to land on Japan’s mainland of Honshu in two years. In terms of the total damage caused by disasters in 2009, 208 people were killed or unaccounted for, 4,681 houses were damaged or destroyed, and 21,900 houses were flooded. The total damage amounted to 104.0 billion yen (breakdown: 88.0 billion yen agricultural, 11.7 billion yen forestry and 4.2 billion yen fishery damages).

This section, including Table 1.2.2, summarizes the major meteorological disasters of 2009 and their causes.

Table 1.2.3 shows damage caused by meteorological disasters from 2000 to 2009.

- Prolonged rainy days, low temperatures and short sunshine durations (July – August)
  As low-pressure systems and the Okhotsk high greatly influenced Hokkaido from July to August, significantly below-normal temperatures, considerably above-normal precipitation and below-normal sunshine durations were observed. These led to lower yields and quality loss in many crops, including rice crop sterility in many areas due to low water temperatures, pre-harvest sprouting of wheat due to rainfall in the harvest season, and poor growth of beans due to wet conditions. Agricultural damage amounted to 59.5 billion yen.

- Heavy rainfall (19 – 26 July)
  The stationary Baiu front became active over western Japan from 19 to 26 July, bringing remarkably heavy rainfall in and around Yamaguchi Prefecture on 21 July and heavy rainfall around northern Kyushu from 24 to 26 July. Eleven observation stations from Chugoku to northern Kyushu reported record hourly maximum precipitation amounts, and some recorded nearly twice their normal precipitation amounts for July.
  A total of 39 fatalities or people missing, 378 damaged houses and 11,524 flooded houses were reported. Agricultural damage amounted to 6.5 billion yen. JMA gave this heavy rainfall the official name of The Chugoku and Northern Kyushu Heavy Rainfall of July 2009.

- Typhoon ETAU (0909) (8 – 11 August)
  ETAU (0909) formed as a tropical depression (TD) in the south of Japan on 8 August. As it moved northward, it was upgraded to typhoon (TY) status at 15 JST on 9 August. It passed south of the Kii Peninsula on 10 August and south of the Tokai and Kanto regions on 11 August before advancing to eastern Japan. The TD/TY and the humid air mass around it brought heavy rain from the Kyushu to the Tohoku regions from 8 to 11 August.
  Local heavy rainfall was observed in the Shikoku, Chugoku, Kinki and Kanto regions. Eleven observation stations reported record hourly maximum precipitation amounts, and five experienced two to three times their normal monthly precipitation amounts for August during this period.
  A total of 27 fatalities or people missing, 1,165 damaged houses and 4,468 flooded houses were reported. Forestry damage amounted to 5.6 billion yen.
Typhoon MELOR (0918) (6 – 9 October)

Typhoon MELOR (0918) formed to the east of the Mariana Islands at 09 JST on 30 September. After recurving northward, it advanced to the south of Minamidaito Island on 6 October and to the south of Shikoku on 7 October. It landed near the Chita Peninsula on 8 October and passed over the Tokai, Kanto-Koshin and Tohoku regions before advancing to the Pacific Ocean and transforming into an extratropical cyclone on the evening of the same day. It approached the Chishima Islands on 9 October.

As MELOR (0918) approached the Nansei Islands and the western part of Japan with no loss of intensity, it brought strong winds over a wide area from Okinawa to Hokkaido. With the passage of MELOR (0918), some parts of the Kinki region experienced total precipitation amounts of more than 300 mm from 6 to 9 October, and 21 observation stations reported record wind speeds. Tornadoes were also generated in Ibaraki and Chiba prefectures on the morning of 8 October from the developed clouds surrounding MELOR (0918).

A total of 6 fatalities or people missing, 2,325 damaged houses and 3,310 flooded houses were reported. Agricultural damage amounted to 16.6 billion yen.

| Table 1.2.2  Major meteorological disasters in Japan in 2009 and related damage |
|-------------------------------------------------|-----------------|-----------------|-----------------|-----------------|
| **Type**                                        | **Date**        | **Region**      | **Fatalities or people missing** | **Houses damaged** | **Houses flooded** | **Agricultural** | **Fishery** | **Forestry** | **Total** |
| Prolonged rainy days, low temperatures and short sunshine durations | Jul. – Aug.    | Hokkaido        | 0                              | 0                | 0                | 59.5            | 0           | 0           | 0         |
| Heavy rainfall                                  | 19 – 26 Jul.   | Kanto – Northern Kyushu | 39                            | 378              | 11,524           | 6.5             | 0.1         | 3.7         | 10.2      |
| Typhoon                                         | 8 – 11 Aug.    | Tohoku – Northern Kyushu | 27                            | 1,165            | 4,468            | 1.2             | 0           | 5.6         | 6.9       |
| Typhoon                                         | 6 – 9 Oct.     | Whole country    | 6                             | 2,325            | 3,310            | 16.6            | 3.0         | 2.2         | 21.7      |
| Total                                           |                 |                 | 208                           | 4,681            | 21,900           | 88.0            | 4.2         | 11.7        | 104.0     |

Note: This table summarizes meteorological disasters with more than five fatalities or people missing, more than 1,000 damaged/flooded houses or more than JPY 10 billion in agricultural damage. The totals also include meteorological disasters not listed above.
<table>
<thead>
<tr>
<th>Year</th>
<th>Fatalities or people missing</th>
<th>Houses damaged</th>
<th>Houses flooded</th>
<th>Amount of damage (billions of yen)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Agricultural</td>
</tr>
<tr>
<td>2000</td>
<td>63</td>
<td>1,755</td>
<td>82,585</td>
<td>43.3</td>
</tr>
<tr>
<td>2001</td>
<td>110</td>
<td>1,804</td>
<td>12,936</td>
<td>51.6</td>
</tr>
<tr>
<td>2002</td>
<td>85</td>
<td>2,919</td>
<td>16,194</td>
<td>80.9</td>
</tr>
<tr>
<td>2003</td>
<td>145</td>
<td>3,122</td>
<td>16,151</td>
<td>277.7</td>
</tr>
<tr>
<td>2004</td>
<td>327</td>
<td>103,458</td>
<td>172,504</td>
<td>296.3</td>
</tr>
<tr>
<td>2005</td>
<td>162</td>
<td>7,829</td>
<td>27,199</td>
<td>56.7</td>
</tr>
<tr>
<td>2006</td>
<td>319</td>
<td>19,254</td>
<td>14,729</td>
<td>53.1</td>
</tr>
<tr>
<td>2007</td>
<td>151</td>
<td>2,757</td>
<td>11,273</td>
<td>40.1</td>
</tr>
<tr>
<td>2008</td>
<td>146</td>
<td>1,677</td>
<td>34,310</td>
<td>9.8</td>
</tr>
<tr>
<td>2009</td>
<td>208</td>
<td>4,681</td>
<td>21,900</td>
<td>88.0</td>
</tr>
</tbody>
</table>
2.3 Surface temperature and precipitation in Japan

Long-term changes in surface temperature and precipitation in Japan are analyzed using observational records from 1898 onwards. Table 1.2.4 lists the meteorological stations whose data are used to derive annual mean surface temperatures and total precipitation amounts. To calculate long-term temperature trends, JMA selected 17 stations that are considered not to have been highly influenced by urbanization and have continuous records from 1898 onwards. Among these, however, Miyazaki and Iida were moved in May 2000 and May 2002 respectively, and their temperatures have been adjusted to exclude the influence of these transfers. To calculate long-term precipitation trends, 51 stations that also have continuous records from 1898 onwards were selected.

Table 1.2.4 Observation stations whose data are used to calculate surface temperature anomalies and precipitation ratios in Japan

<table>
<thead>
<tr>
<th>Observation stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature 17 stations</td>
</tr>
<tr>
<td>Precipitation 51 stations</td>
</tr>
</tbody>
</table>

The mean surface temperature in Japan for 2009 is estimated to have been 0.56°C above normal (i.e. the 1971 – 2000 average), which is the seventh warmest on record since 1898. The temperature anomaly has been rising at a rate of about 1.13°C per century since instrumental temperature records began in 1898 (Figure 1.2.3). Despite using only data from 17 carefully selected stations, the analysis does not entirely eliminate the influence of urbanization. In particular, temperatures have rapidly increased since the late 1980s. The high temperatures in recent years have been influenced by fluctuations over different time scales ranging from several years to several decades, as well as by global warming caused by an increase in greenhouse gases such as CO₂. This trend is almost the same as that of worldwide temperatures, as described in Section 1.2.

The ratio of annual precipitation to the normal in 2009 was 99%. Japan received relatively large amounts of rainfall until the mid-1920s and around the 1950s, and fluctuations have gradually increased since the 1970s (Figure 1.2.4). The variance seen in recent years has been significantly larger than that observed in the early 20th century.
Figure 1.2.3  Annual surface temperature anomalies from 1898 to 2009 in Japan. The bars indicate anomalies from the normal (i.e. the 1971 – 2000 average of the 17 stations). The blue line indicates the five-year running mean, while the red line indicates the long-term trend.

Figure 1.2.4  Annual precipitation ratios from 1898 to 2009 in Japan. The bars indicate annual precipitation ratios to the normal (i.e. the 1971 – 2000 average of the 51 stations). The green line indicates the five-year running mean.
2.4 Long-term trends of extreme events in Japan

The trends of extreme climatic events in Japan are described in this section: extreme monthly mean temperatures and monthly precipitation amounts, and the number of days with extreme temperatures or precipitation amounts above certain thresholds (e.g. 30°C, 100 mm). The observation stations used for this research are the same as the 17 for temperature and the 51 for precipitation listed in Section 2.3 (see Table 1.2.4). Monthly mean temperatures for Miyazaki and Iida have been corrected to exclude the influence of their transfers. However, the 15 observation stations other than Miyazaki and Iida are referred to in Sections 2.4.1 (2) and (3) due to difficulties in correcting the daily maximum/minimum temperatures.

2.4.1 Long-term trend of extreme temperatures

(1) Extreme monthly mean temperatures

Figure 1.2.5 shows annual occurrences of extremely high/low monthly mean temperatures over the 109-year period from 1901 to 2009. Table 1.2.5 shows the long-term trends over the whole period, the averages for the first 30 years of the 20th century (1901 – 1930) and those for the most recent 30-year period (1980 – 2009).

Here, the threshold of extremely high/low temperature is defined as the fourth-highest/lowest value for the month over 109 years. The annual number of extremely high/low temperatures is calculated by dividing the total number of occurrences by the total number of available stations in that year (i.e. it is equivalent to the occurrence per station). Additionally, the frequency of occurrence of the highest to the fourth-highest values over the 109-year period is once every 27 years, which is close to the extreme event occurrence frequency of once every 30 years. The average occurrence of extreme values in a year is expected to be approximately \( (1/27) \times 12 \) months = 0.44 (represented by the dashed black horizontal line in Figure 1.2.5).

The occurrence of extremely high/low temperatures increased/decreased significantly during the period 1901 – 2009.

The occurrence of extremely high temperatures increased remarkably from the 1980s onward, and the average of the most recent 30-year period (i.e. 1980 – 2009) reached six times that seen at the beginning of the 20th century (i.e. 1901 – 1930). Conversely, the occurrence of extremely low temperatures in the most recent 30-year period decreased to about 30% of that seen at the beginning of the 20th century.
Figure 1.2.5  Annual number of occurrences of extremely high/low monthly mean temperatures
The annual number of occurrences of the highest/lowest first-to-fourth values for each month during the period 1901 – 2009 are indicated. The thin blue/red lines indicate the annual occurrence of extremely high/low monthly mean temperatures divided by the total number of monthly observation data sets available in the year (i.e. the average occurrence per station). The thick blue/red lines indicate the 11-year running mean value. The thick dashed black line indicates the expected frequency of the highest/lowest first-to-fourth values for each year over the 109-year period.

Table 1.2.5  Long-term trends of extremely high/low monthly mean temperatures
The long-term trend refers to the linear trend and the occurrence per station per ten-year period. An asterisk (*) means that the trend is significant with a 95% confidence level. The average occurrence per station during the first 30 years of the 20th century (i.e. 1901 – 1930) and the most recent 30-year period (i.e. 1980 – 2009) are also indicated.

<table>
<thead>
<tr>
<th>Extremely high monthly mean temperatures</th>
<th>Extremely low monthly mean temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trend for 1901 – 2009: Average for 1901 – 1930</td>
<td>Average for 1901 – 1930 0.16</td>
</tr>
<tr>
<td>+0.10/10 years (*) Average for 1980 – 2009</td>
<td>0.95</td>
</tr>
<tr>
<td>Trend for 1901 – 2009: Average for 1901 – 1930</td>
<td>Average for 1980 – 2009 0.72</td>
</tr>
<tr>
<td>-0.07/10 years (*)</td>
<td>0.20</td>
</tr>
</tbody>
</table>
(2) Annual number of days with maximum temperatures of $\geq 30^\circ C$ and $\geq 35^\circ C$

Figures 1.2.6 and 1.2.7 show the averages (over 15 stations) of the annual number of days with maximum temperatures (Tmax) of $\geq 30^\circ C$ and $\geq 35^\circ C$ in the 79-year period from 1931 to 2009. Table 1.2.6 shows the long-term trend over the whole period and average values for the first 30 years of the period (1931 – 1960) and for the most recent 30-year period (1980 – 2009).

The annual number of days with Tmax $\geq 30^\circ C$ shows no significant trend in the period 1931 – 2009, and there is little difference between the average of the first 30 years and that of the most recent 30-year period. However, an increasing trend has been seen since the 1980s, and recent 11-year averages have been in the highest range since 1931.

The annual number of days with Tmax $\geq 35^\circ C$ increased significantly in the period 1931 – 2009, and the average of the most recent 30-year period reached 1.6 times that of 1931 – 1960. The level increased in the 1980s, and has often been more than two days per station since the middle of the 1990s.

Table 1.2.6  Long-term trends in the annual number of days with maximum temperatures of $\geq 30^\circ C$ and $\geq 35^\circ C$

The table is the same as Table 1.2.5, except the trend during the period 1931 – 2009 is indicated as the change every 10 years (unit: days/station). The average number of occurrences per station in the first 30 years (1931 – 1960) and the most recent 30-year period (1980 – 2009) are also indicated.

| Annual number of days with Tmax $\geq 30^\circ C$ | | | |
|---|---|---|
| Trend for 1931 – 2009: | Average for 1931 – 1960 | 36.5 days |
| +0.15 days/10 years | Average for 1980 – 2009 | 36.6 days |

| Annual number of days with Tmax $\geq 35^\circ C$ | | | |
|---|---|---|
| Trend for 1931 – 2009: | Average for 1931 – 1960 | 1.0 days |
| +0.13 days/10 years (*) | Average for 1980 – 2009 | 1.6 days |
Figure 1.2.6  Annual number of days with maximum temperatures of $\geq 30^\circ$C
Annual number of days per station. The thin line indicates the value for each year, and the thick line indicates the 11-year running mean value.

Figure 1.2.7  Annual number of days with maximum temperatures of $\geq 35^\circ$C
As per Figure 1.2.6, but for maximum temperatures of $\geq 35^\circ$C
(3) Annual number of days with minimum temperatures of $< 0^\circ C$ and $\geq 25^\circ C$

Figures 1.2.8 and 1.2.9 show the averages (over 15 stations) of the annual number of days with minimum temperatures ($T_{\text{min}}$) of $< 0^\circ C$ and $\geq 25^\circ C$ in the 79-year period from 1931 – 2009. Table 1.2.7 shows the long-term trends over the whole period, the average values for the first 30 years of the 20th century (1901 – 1930) and those for the most recent 30-year period (1980 – 2009).

The annual number of days with $T_{\text{min}} < 0^\circ C$ decreased significantly, and the average for the most recent 30-year period is about 86% of the value for the first 30 years. Conversely, the annual number of days with $T_{\text{min}} \geq 25^\circ C$ increased significantly, and the average for the most recent 30-year period is 1.6 times the level seen in the first 30 years.

![Graph](image)

Figure 1.2.8  Annual number of days with minimum temperatures of $< 0^\circ C$

As per Figure 1.2.6, but for minimum temperatures of $< 0^\circ C$
Table 1.2.7 Long-term trends in the annual number of days with minimum temperatures of < 0°C and ≥ 25°C
As per Table 1.2.6, but for minimum temperatures of < 0°C and ≥ 25°C

<table>
<thead>
<tr>
<th>Annual number of days with Tmin &lt; 0°C</th>
<th>Annual number of days with Tmin ≥ 25°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2.33 days/10 years (*)</td>
<td>+1.28 days/10 years (*)</td>
</tr>
<tr>
<td>Average for 1931 – 1960</td>
<td>Average for 1931 – 1960</td>
</tr>
<tr>
<td>96.8 days</td>
<td>11.0 days</td>
</tr>
<tr>
<td>60.0 days</td>
<td>17.1 days</td>
</tr>
</tbody>
</table>

2.4.2 Long-term trends in extreme precipitation amounts

(1) Extreme monthly precipitation amounts

Figure 1.2.10 shows annual occurrences of extremely heavy/light monthly precipitation amounts over the 109-year period from 1901 to 2009. Table 1.2.8 shows the long-term trend for the whole period, average values in the first 30 years of the 20th century (1901 – 1930) and those for the most recent 30-year period (1980 – 2009). Here, the threshold of extremely heavy/light monthly precipitation amounts is the same as that used for extreme temperatures, i.e. the fourth-highest/lowest values in the 109-year period.

The occurrence of extremely light monthly precipitation amounts increased significantly in the period 1901 – 2009, but extremely heavy monthly precipitation amounts show no significant trend. The occurrence of extremely light monthly precipitation amounts in the most recent 30-year period increased to about 1.6 times the level seen in the first 30 years of the 20th century. The occurrence of extremely heavy/light monthly precipitation amounts shows a negative correlation until around the 1980s.
Figure 1.2.10  Annual number of occurrences of extremely heavy/light monthly precipitation amounts
As per Figure 1.2.5, but for monthly precipitation amounts

Table 1.2.8  Long-term trends in extremely heavy/light monthly precipitation amounts
As per Table 1.2.5, but for monthly precipitation amounts

<table>
<thead>
<tr>
<th></th>
<th>Extremely heavy monthly precipitation</th>
<th>Extremely light monthly precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trend for 1901 – 2009:</td>
<td>Average for 1901 – 1930: 0.48</td>
<td>Average for 1901 – 1930: 0.36</td>
</tr>
<tr>
<td>0.00/10 years</td>
<td>Average for 1980 – 2009: 0.45</td>
<td>Average for 1980 – 2009: 0.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Figures 1.2.11 and 1.2.12 show averages over 51 stations for the annual number of days with precipitation of ≥ 100 mm and ≥ 200 mm during the 109-year period from 1901 to 2009. Table 1.2.9 shows the long-term trends over the whole period, averages for the first 30 years of the 20th century (1901 – 1930) and those for the most recent 30-year period (1980 – 2009).

The annual number of days with precipitation of ≥ 100 mm increased significantly in the period 1901 – 2009, while the figure for ≥ 200 mm shows no significant trend. The average annual number of days with precipitation of ≥ 100 mm in the most recent 30-year period increased to about 1.2 times the level seen in the first 30 years of the 20th century.
Figure 1.2.11  Annual number of days with precipitation of ≥ 100 mm
As per Figure 1.2.6, but for precipitation of ≥ 100 mm

Figure 1.2.12  Annual number of days with precipitation of ≥ 200 mm
As per Figure 1.2.6, but for precipitation of ≥ 200 mm
Table 1.2.9  Long-term trends in the annual number of days with precipitation of $\geq 100$ mm and $\geq 200$ mm
As per Table 1.2.6, but for precipitation of $\geq 100$ mm and $\geq 200$ mm

<table>
<thead>
<tr>
<th></th>
<th>Annual number of days with precipitation of $\geq 100$ mm</th>
<th>Annual number of days with precipitation of $\geq 200$ mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trend for 1901 – 2009:</td>
<td>Average for 1901 – 1930: 0.84 days</td>
<td>Average for 1901 – 1930: 0.07 days</td>
</tr>
<tr>
<td>$+$0.02 days/10 years (*)</td>
<td>Average for 1980 – 2009: 1.01 days</td>
<td>Average for 1980 – 2009: 0.10 days</td>
</tr>
</tbody>
</table>

**Column - Long-term trend of heavy rainfall analyzed using AMeDAS data**

The Japan Meteorological Agency observes precipitation at one-hour intervals at about 1,300 regional meteorological observing stations (collectively known as the Automated Meteorological Data Acquisition System, or AMeDAS) all over Japan. Observation was started in the latter part of the 1970s at many points. Although the period covered by AMeDAS data is shorter than that of Local Meteorological Observatories or Weather Stations (which have records going back about 100 years), AMeDAS has about nine times as many stations. It is therefore relatively easier to catch localized heavy precipitation using AMeDAS data.

Here, long-term changes in the frequency of heavy rainfall over the most recent 30-year period covered by AMeDAS can be ascertained by tallying up the frequency of days with over 200 mm and over 400 mm of heavy rain, and the frequency of hours with over 50 mm and over 80 mm of strong rain observed by AMeDAS every year. The number of AMeDAS points has been about 1,300 since 1979, though the total in 1976 was about 1,100. We therefore normalize the data into rain frequencies per 1,000 points to eliminate the influence of differences in the number of points from year to year.

The change in the frequency of strong hourly rain is shown in Figure 1.2.13, and the change in the frequency of heavy daily rain is shown in Figure 1.2.14. The 11- or 12-year average values (shown by the horizontal red line in the graph) show a gradual increase in all cases. Additionally, statistical significance is found in the increasing tendency for frequencies of over 50 mm of strong hourly rain, but not for frequencies of over 80 mm of strong hourly rain or those of over 200 mm and over 400 mm of heavy daily rain.

Since the observation period of AMeDAS is short and the frequencies of heavy and strong rain change considerably every year, further data accumulation is necessary to accurately capture the long-term trend.
Figure 1.2.13 Frequency of rainfall over 50 and 80 mm/hour (yearly, per 1,000 AMeDAS points)
Figure 1.2.14  Frequency of rainfall over 200 and 400 mm/day (yearly, per 1,000 AMeDAS points)
**Column – Distribution of trends in extreme temperatures analyzed using AMeDAS data from the most recent 31-year period**

Long-term trends in extreme temperatures observed at 15 stations in Japan show a warming tendency, especially over the last 30 years. The Japan Meteorological Agency conducted research on the distribution of these trends in Japan using data collected from 1979 to 2009 at 402 AMeDAS stations whose locations had not changed for 31 years.

Annual mean temperatures show a significant increasing trend at a rate of 0.3 – 0.6°C per decade at most stations (Figure 1.2-15 (a)). In particular, the rate of increase is large from Tokyo to Saitama (in the Kanto-Koshin region), around the Seto Inland Sea (between the Chugoku and Shikoku regions) and in the Northern part of Kyushu (see Map 1 at the end of the report).

Figure 1.2-15 (b) shows the distribution of the trend in the annual number of days with maximum temperatures of ≥ 30°C. The number shows no significant increase in Northern Japan, where temperatures rarely reach or exceed 30°C. In other areas, the number shows a significant trend of increase at a rate of 2 – 12 days per decade at most stations. The rate of increase is large from Western Japan to Okinawa and Amami. The annual number of days with maximum temperatures of ≥ 35°C shows a remarkable increasing trend from Tokyo to Saitama, over the Nōbi Plain (in the Tokai region) and in the Northern part of Kyushu at a rate of 2 – 4 days per decade (Figure 1.2-15 (c)). The annual number of days with minimum temperatures of ≥ 25°C also shows a remarkable increasing trend around the Seto Inland Sea, in the Northern part of Kyushu and in Okinawa/Amami (Figure 1.2-15 (d)).

The annual number of days with minimum temperatures of < 0°C shows a decreasing trend at many stations (Figure 1.2-15 (e)). The rate of decrease is large around Tokyo and in the northern part of Kyushu. However, there is no significant trend in the number at some stations because temperatures rarely fall below 0°C in Okinawa and Amami, and the year-on-year variation in the number is larger than its trend in other areas.

Several parameters for extreme temperatures show remarkable warming in the northern part of Kyushu and around the Seto Inland Sea. However, it is not clear how the high temperatures seen in recent years have been influenced by natural fluctuations, urbanization and global warming. The annual number of days with maximum temperatures of ≥ 35°C shows a remarkable increasing trend from Tokyo to Saitama and over the Nōbi Plain. Although metropolitan areas are found in both regions, further study is needed to clarify whether the high temperatures seen in recent years have been influenced by urbanization.
Figure 1.2-15  Trends of extreme temperatures over the 31-year period from 1979 to 2009 at 402 AMeDAS stations (a) annual mean temperature, annual numbers of days with maximum temperatures of (b) \( \geq 30^\circ C \) and (c) \( \geq 35^\circ C \), and annual numbers of days with minimum temperatures of (d) \( \geq 25^\circ C \) and (e) \( < 0^\circ C \)

Solid squares denote significant values at a 95% confidence level, and open squares denote insignificant values.
2.5 Tropical cyclones

In 2009, 22 tropical cyclones (TCs) with maximum wind speeds of 17.2 m/s or higher formed. Of these, 8 came within 300 km of the Japanese Archipelago, and 1 made landfall in Japan. The normal statistics (i.e. the 1971 – 2000 averages) for formation, approach and landfall are 26.7, 10.8 and 2.6 respectively.

Figure 1.2.15 shows the tracks of tropical cyclones in 2009. During the year, a near-normal or above-normal number approached Northern Japan and Eastern Japan. In contrast, a below-normal number approached Western Japan, Okinawa and Amami. This was considered a result of weaker expansion of the North Pacific High toward Japan, causing many tropical cyclones to pass south or east of the country.

Figure 1.2.16 shows the number of TCs approaching and hitting Japan since 1951. Although these figures show variations with different time scales, no significant long-term trends are seen. In recent years, the number of TCs forming has been lower than normal.

Figure 1.2.17 shows the number and ratio of tropical cyclones with maximum winds of 33 m/s or higher to those with maximum winds of 17.2 m/s or higher from 1977 (the year from which whole data on maximum wind speeds near the center are available). The number of tropical cyclone formations with maximum winds of 33 m/s or higher varies between 10 and 20, and no particular trend is seen. The ratios vary from about 40% to 60%.

![Figure 1.2.15 Tracks of tropical cyclones in 2009](image-url)

The solid lines represent the tracks of tropical cyclones with maximum winds of 17.2 m/s or higher. The circled numbers indicate points where the maximum wind speed of the tropical cyclone exceeded 17.2 m/s, while those in squares show points where the maximum wind speed fell below 17.2 m/s.
Figure 1.2.16  The number of tropical cyclones with maximum winds of 17.2 m/s or higher forming in the western North Pacific (top), those that approached Japan (middle) and those that hit Japan (bottom). The solid, thick and dashed lines represent annual/five-year running means and normal values (i.e. the 1971 – 2000 average) respectively.

Figure 1.2.17  Number (bottom) and ratio (top) of tropical cyclone formations with maximum winds of 33 m/s or higher. The thin and thick lines represent annual and five-year running means respectively.
2.6 The urban heat island effect in metropolitan areas of Japan

With the aim of contributing to the formulation of policies designed to mitigate the urban heat island (UHI) effect, the Japan Meteorological Agency (JMA) has conducted research into how UHI actually influences urban climates and what kind of weather conditions are likely to aggravate its impact. In this section, temperature trends and the situation for 2009 at metropolitan stations in Japan are illustrated.

Table 1.2.10 lists the rates of change in annual average temperatures, monthly average temperatures for January and August, annual averages for daily maximum and minimum temperatures, and annual numbers of days with minimum temperatures of $\geq 25^\circ C$ and $< 0^\circ C$ at metropolitan stations in Japan with annual numbers of days for 2009. Such rates of change averaged over stations in medium-size and small cities considered not to have been highly influenced by urbanization (see Table 1.2.4; hereafter, “rural stations”) are also listed.

Temperatures at metropolitan stations are rising more rapidly than average values at rural stations. This difference between metropolitan and rural stations is considered to be caused by the UHI effect (although, to be exact, rural stations are also somewhat influenced by this effect). The increase in temperatures for January is larger than that for August, and the rates of increase for daily minimum temperatures are larger than those for daily maximum temperatures. Generally speaking, the difference in temperature between urban and rural stations in winter is larger than that in summer. The nighttime difference is also larger than the corresponding figure for the daytime. This pattern is clearly observed for temperatures at metropolitan stations in Japan.

The numbers of days with minimum temperatures of $\geq 25^\circ C$ show a remarkable increase except in Sapporo and Sendai, while those with minimum temperatures of $< 0^\circ C$ show a decrease at all metropolitan stations. These trends are considered to be significantly influenced by the UHI effect as well as by global warming.

In the summer of 2009, because the North Pacific High around Japan was weak, the number of days with minimum temperatures of $\geq 25^\circ C$ in metropolitan areas was near or below normal (e.g. 0 for Niigata (normal: 8.4 days)) except for Kagoshima with 53 (17.2 days above normal). In the winter of 2009, because the northwesterly winter monsoon was weak, the number of days with minimum temperatures of $< 0^\circ C$ for most metropolitan areas was 10 to 20 days lower than normal (e.g. 0 for Tokyo, Osaka and Kagoshima (normals: 10.2, 10.1 and 9.7 respectively) and 15 for Nagoya (20.6 days below normal)).
Table 1.2.10  Rates of change in annual average temperatures, monthly average temperatures for January and August, annual averages for daily maximum and minimum temperatures, and annual numbers of days with minimum temperatures of \( \geq 25^\circ \text{C} \) and \( < 0^\circ \text{C} \) in metropolitan stations of Japan with annual numbers of days in 2009. These are based on data from 1931 to 2009. The rates averaged over rural stations (see Table 1.2.4) are also listed. Italics represent statistical insignificance. For cities marked with “*” (including the rural stations of Iida and Miyazaki), the rates of change were calculated after adjustment\(^2\) to remove the effects of station relocation, and the rates for annual numbers were not calculated. Thus, the rural station temperature is the 17-station average including Iida and Miyazaki temperatures adjusted for the effects of relocation, but the rural-station annual number of days is the 15-station average excluding data from Iida and Miyazaki. Values in parentheses for the annual numbers of days indicate the deviation from the normal.

<table>
<thead>
<tr>
<th>City</th>
<th>Temperature</th>
<th></th>
<th>Annual number of days</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rates of change (°C/100 years)</td>
<td>Rates of change (days/10 years)</td>
<td>2009</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>Daily max.</td>
<td>Daily min.</td>
<td>Tmin ≥ 25°C</td>
</tr>
<tr>
<td>Sapporo</td>
<td>2.6</td>
<td>3.8</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Sendai</td>
<td>2.3</td>
<td>3.2</td>
<td>0.3</td>
<td>0.9</td>
</tr>
<tr>
<td>Tokyo</td>
<td>3.3</td>
<td>4.8</td>
<td>1.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Niigata*</td>
<td>2.1</td>
<td>2.8</td>
<td>1.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Nagoya</td>
<td>2.9</td>
<td>3.4</td>
<td>2.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Osaka*</td>
<td>2.9</td>
<td>2.7</td>
<td>2.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Hiroshima*</td>
<td>2.1</td>
<td>2.2</td>
<td>1.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Fukuoka</td>
<td>3.2</td>
<td>3.3</td>
<td>2.3</td>
<td>1.6</td>
</tr>
<tr>
<td>Kagoshima*</td>
<td>3.0</td>
<td>3.4</td>
<td>2.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Rural stations*</td>
<td>1.5</td>
<td>1.9</td>
<td>0.7</td>
<td>0.9</td>
</tr>
</tbody>
</table>

\(^2\) This adjustment was calculated through principal component analysis, which was used to remove the effects of station relocation when the normal values were updated in 2000.
Part II  Oceans

Oceans, which cover about 70 percent of the earth's surface and have a high heat storage capacity, are a major component of the climate system and significantly influence the motion of the atmosphere. In order to monitor oceans, the Japan Meteorological Agency (JMA) conducts various kinds of oceanographic observation such as research vessel surveys and the deployment of ocean data buoys and profiling floats. Based on these observational data as well as satellite observations and reports from voluntary merchant ships and fishing boats, oceanographic conditions such as water temperature distribution and ocean currents are analyzed using advanced technology including numerical models. In addition to the monitoring of these physical parameters, JMA conducts regular surveys to monitor marine pollution. The results of ocean monitoring in 2009 are summarized in this chapter. Details of the monitoring results and recent information are available on the Marine Diagnosis Report website (in Japanese) at http://www.data.kishou.go.jp/kaiyou/shindan/.

1  Global oceans

1.1  Global sea surface temperature

Figure 2.1.1 shows the long-term rising trend (0.50°C per century) in the global average sea surface temperature (SST), represented in the form of departure from the 1971 – 2000 mean. The global average SST departure in 2009 was +0.23°C, which is ranked as the second highest since 1891.

Figure 2.1.2 shows global SST anomalies based on the 1971 – 2000 mean for February, May, August and November of 2009.

In February of 2009, positive SST anomalies were seen from the western tropical region to the 40°N zone in the North Pacific, while negative values were observed in the eastern tropical region. These weakened gradually, and positive anomalies became dominant to the south of 40°N from May to August. The negative anomalies around the Aleutian Islands strengthened and extended to the north of 20°N in the eastern North Pacific in November.

In the equatorial Pacific, negative SST anomalies were observed in central and eastern parts in February. In May, positive values were seen over the whole of the equatorial Pacific. Positive anomalies strengthened in August, and exceeded +1.0°C in central and eastern parts in November.

In the South Pacific, remarkably positive SST anomalies observed around 30°S in February had weakened and shrunk by August. In November, remarkably positive SST anomalies were seen around 40°S and 150°W, and negative anomalies dominated elsewhere.

In the Indian Ocean, positive SST anomalies were seen in most areas and persisted throughout the year, except in the eastern part where negative SST anomalies were observed in February.

In the North Atlantic, negative SST anomalies were seen in the tropical region from February to May. These subsequently disappeared, and positive SST anomalies observed around 30°N extended to the tropical region.
In the South Atlantic, positive SST anomalies were seen in the tropical region throughout the year. In November, remarkably positive anomalies were observed in the east of Brazil.

Figure 2.1.1  Time-series representation of annual global average SST departures from the 1971 – 2000 mean for the period 1891 – 2009. The blue bars represent annual departures, the red line shows the five-year running mean and the green line indicates the long-term linear trend.
1.2 El Niño and La Niña

The term El Niño refers to a climatologic phenomenon in which sea surface temperatures (SSTs) across the region from the central equatorial Pacific to just off the coast of Peru stay above normal for around 6 to 18 months. A contrasting phenomenon in which SSTs in the same area stay below normal is referred to as La Niña.

These two basin-scale phenomena are known to be closely related to variations in the trade winds that blow perpetually westward over the equatorial Pacific Ocean. These trade winds strengthen during La Niña conditions and weaken during El Niño conditions. The determining factor behind the intensity of trade winds is the disparity in sea-level pressure (SLP) between the eastern and western equatorial Pacific. This difference, which fluctuates in a seesawing action, is known as Southern Oscillation. El Niño/La Niña and Southern Oscillation are not independent of each other, but are in fact different manifestations of the same phenomenon in which the atmosphere and the ocean are closely intertwined. The phenomenon as a whole is referred to as El Niño - Southern Oscillation, or ENSO for short.

As changes in SST in the central to the eastern equatorial Pacific are in most cases preceded by changes in the subsurface temperature, it is essential to monitor these changes in order to diagnose the evolution of El Niño/La Niña phenomena.

Figure 2.1.3 (b) shows a time series of monthly mean SST departures from the reference value (defined as the most recent 30-year mean SST) averaged over the El Niño monitoring
region (5°N – 5°S, 150°W – 90°W; see Figure 2.1.3 (a)). After the end of the La Niña event in boreal spring of 2008, monthly mean SSTs were slightly lower than the reference value from December of 2008 to March of 2009. Thereafter, monthly mean SSTs were higher than the reference value, and departures from it exceeded +1.0°C in November and December of 2009. As five-month running mean SST departures have remained at +0.5°C or above since June of 2009, it is considered that an El Niño event has been active since the boreal summer of 2009.

Figure 2.1.3 (c) shows a time-series representation of the Southern Oscillation Index (SOI), which is defined as the difference between SLP anomalies in Tahiti, in the Southern Pacific Ocean and in Darwin, Australia. Generally, SOI swings toward the negative during El Niño events and toward the positive during periods of La Niña. Its value was positive until April of 2009, and stayed around zero thereafter. From October, negative values were seen. The five-month running mean SOI fell from positive to negative through the year.

Figures 2.1.4 (a), (b), (c) and (d) show subsurface water temperatures (SWT) and their anomalies (deviations from the climatological means for the period 1979 – 2004) to a depth of 400 m along the equator in the Pacific Ocean in February, May, August and November of 2009 respectively. Under normal conditions, the thermocline, which is marked by a thin layer where the temperature drops abruptly with depth (roughly equivalent to the depth of the 20°C isothermal line), has an uphill gradient toward the east. In February (Fig. 2.1.4 (a)), negative anomalies (a shallow thermocline) were seen from the central to the eastern part, and remarkably positive anomalies (a deep thermocline) were observed in the western part. Thereafter, positive anomalies extended to the eastern part and became dominant throughout the whole region in May (Fig. 2.1.4 (b)). In August (Fig. 2.1.4 (c)), negative anomalies were seen in the eastern part, and remarkably positive anomalies were seen from the western to the central parts. In November (Fig. 2.1.4 (d)), remarkably positive anomalies were observed from the central to the eastern parts, and negative anomalies were seen in the western part.
Figure 2.1.3 (a) The El Niño monitoring region (5°N – 5°S, 150°W – 90°W; shaded in orange) and the locations of Darwin (Australia) and Tahiti, (b) time-series representation of monthly mean SST departures (°C) from the reference value (defined as the most recent 30-year mean SST) averaged over the El Niño monitoring region, and (c) time-series representation of the Southern Oscillation Index for 1980 – 2009. The thin lines represent the monthly mean, and the thick lines show the five-month running mean. The durations of El Niño events (defined as periods during which the five-month running mean SST departure stays above +0.5°C for six consecutive months) are shown as red boxes, and those of La Niña events (when the value stays below –0.5°C for six consecutive months) are shown as blue boxes in (b). The red and blue areas in (c) designate periods of negative and positive SOI respectively.
Figure 2.1.4  Longitude-depth plots for subsurface water temperatures and their anomalies along the equator in the Pacific Ocean for (a) February, (b) May, (c) August and (d) November of 2009. Anomalies are based on the 26-year mean from 1979 to 2004.
1.3 Sea ice in Arctic and Antarctic areas

Figure 2.1.5 shows interannual variations of the minimum and annual mean sea ice extent in the Arctic Ocean (including the Sea of Okhotsk and the Bering Sea) from 1979 to 2009 along with interannual variations of the annual mean sea ice extent in the Antarctic Ocean.

In the Arctic Ocean, the sea ice extent has followed a significant long-term downward trend since 1979. In particular, this reduction is keenly noted in summertime when the sea ice extent is at its lowest (the minimum sea ice extent). The rate of decrease in the minimum up to 2009 was $8.3 \times 10^4$ km$^2$ per year, and the rate of decrease in the annual mean until the same time was $6.1 \times 10^4$ km$^2$ per year. In 2009, the seasonal minimum sea ice extent in the Arctic Ocean was $513 \times 10^4$ km$^2$, which was the third-lowest value recorded (after 2007 and 2008) since statistics began in 1979.

Meanwhile, the annual mean sea ice extent in the Antarctic Ocean has shown a slight increase at a rate of $1.5 \times 10^4$ km$^2$ per year.

![Figure 2.1.5](image)

**Figure 2.1.5** Time-series representations of minimum and annual mean sea ice extents in the Arctic Ocean (including the Sea of Okhotsk and the Bering Sea) from 1979 to 2009 and the annual mean sea ice extent in the Antarctic Ocean. The broken blue lines indicate the sea ice extent (i.e., the minimum sea ice extent in the Arctic Ocean, the annual mean sea ice extent in the Arctic Ocean and the annual mean sea ice extent in the Antarctic Ocean from the top). The dashed lines indicate the linear trend of each. The sea ice extent is based on data from the Scanning Multifrequency Microwave Radiometer (SMMR) on board NIMBUS-7 from November 1978 to July 1987 and the Special Sensor Microwave/Imager (SSM/I) on board the Defense Meteorological Satellite Program (DMSP) from July 1987 to December 2009.
2 The western North Pacific and the seas adjacent to Japan

2.1 Sea surface temperature and ocean currents in the western North Pacific

2.1.1 Sea Surface Temperature

Figure 2.2.1 shows the rates of increase in the annual mean SST around Japan by area for the period 1900 to 2009 (°C/100 years). SSTs have risen statistically significantly by +0.7°C to +1.7°C over the most recent period of almost 100 years in the seas around Kyushu and the Okinawa Islands, central and southern parts of the Sea of Japan and the seas south of Japan. The rate of increase in SSTs in the seas around Japan is higher than that of the global ocean (0.5°C/100 years).

Figure 2.2.1 Rates of mean SST rise from 1900 to 2009 (°C/100 years)
Areas with an asterisk are those where no significant values have been estimated due to large SST variability factors such as decadal oscillation.

Figures 2.2.2 (a), (b), (c) and (d) show monthly mean SST anomalies for February, May, August and November 2009 respectively. In January, SSTs in the seas adjacent to Japan were below normal in the south of the Okinawa Islands and east of Honshu. From February (Fig. 2.2.2 (a)) to March, as the northwesterly winter monsoon was not active in addition to the cold surge and the influence of cyclones being weak, an area of positive SST anomalies extended in areas other than the sea east of Honshu. From April to July, as shown in Fig. 2.2.2 (b) for May, SSTs became below normal in the area from the seas south of Japan to the seas
south of the Okinawa Islands. Due to an active seasonal rain front associated with cyclones and a moist airstream, negative SST anomalies extended from northern to western Japan in July in the Sea of Japan, the sea east of Japan and the southern part of the Sea of Okhotsk. On the other hand, an area of positive SST anomalies extended in the sea south of Japan and around Chichijima Island. In August (Fig. 2.2.2 (c)), negative SST anomalies continued in the southern part of the Sea of Japan and the southern part of the Sea of Okhotsk as a result of weak expansion of the Pacific anticyclone to areas near Honshu. On the other hand, an area of positive SST anomalies extended in the sea around the Okinawa Islands over a cloud-free area. In September, the passage of typhoons caused the area of negative SST anomalies to extend to the east of Honshu and the south of Japan. In October, November (Fig. 2.2.2 (d)) and December, SSTs in the seas adjacent to Japan were mostly above normal.

Figure 2.2.2 Monthly mean SST anomalies (°C) based on the 1971 – 2000 mean in the western North Pacific for (a) February, (b) May, (c) August and (d) November of 2009
2.1.2 Ocean Currents

(1) The Kuroshio

The Kuroshio (defined as the line of maximum current speed) off the southern coast of Honshu flowed southeastward off the Tokai region, eastward south of Hachijo Island and northward east of the Izu Ridge from January to August. From August to November, it moved gradually northward off the Tokai region and flowed adjacent to Hachijo Island at the end of September. From October to mid-November, it flowed northeastward between Miyake Island and Hachijo Island. After the end of November, it flowed in the vicinity of Hachijo Island. From mid-August to the beginning of October, it flowed far off the coast of the Boso Peninsula. From the beginning of June to the beginning of August and from mid-September to mid-November, it took a slightly meandering path east of Kyushu. The meander moved eastward without further development and disappeared to the south of Shikoku.

(2) The Oyashio

In January and February, the southernmost position of the Oyashio (with temperatures of less than 5°C at 100 m depth) was normal. From March to May, the Oyashio remained in an area around 40°N north of normal. From June to the beginning of August, although it usually moves northward, this time it moved gradually southward and positioned itself south of normal. Notably, from the end of July to the beginning of August it reached as far as 38.5°N. After mid-August, its southernmost position was mostly normal or north of normal. The area of Oyashio cold water was normal or smaller than normal throughout 2009.

2.2 Sea level around Japan

According to the Working Group I contribution to the IPCC (Intergovernmental Panel on Climate Change) Fourth Assessment Report released in February 2007, the global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm/year from 1961 to 2003. The rate was faster from 1993 to 2003 at about 3.1 [2.4 to 3.8] mm/year (the values in square brackets show the range of uncertainty with a 90% confidence interval).

Unlike the global average, however, no clear rise in sea level has been seen along the Japanese coast over the last 100 years, as shown in Figure 2.2.3. The maximum sea level appears around 1950, and near-20-year (bidecadal) variation is dominant. In contrast to the globally averaged rate noted in the IPCC report, the rate along the Japanese coast was 0.8 [0.3 to 1.3] mm/year from 1961 to 2003 and 4.9 [2.1 to 7.7] mm/year from 1993 to 2003.

Figure 2.2.3 shows the tide gauge stations less affected by crustal movement along the Japanese coast.

The annual mean sea level around Japan in 2009 was 37 mm higher than the normal value (i.e. the mean from 1971 to 2000), and is ranked as the fourth highest since 1960. The sea level around Japan has remained higher than normal since the second half of the 1990s.
Figure 2.2.3  Time-series representation of annual mean sea-level values (1906 – 2009) and the location of tide gauge stations

Tide gauge stations assessed as being affected to a lesser extent by crustal movement are selected. The four stations shown in the map on the left are selected for the period from 1906 to 1959 and the 16 stations shown on the right are for the period after 1960. From 1906 to 1959, a time-series representation of the mean value of the annual mean sea-level anomalies for the selected stations is shown. For the period after 1960, cluster analysis was first applied to sea-level observation data for the selected stations along the Japanese coast, then the Japanese islands were divided into the four regions listed below according to sea-level variation characteristics, the annual mean sea-level anomalies were averaged for the four regions, and the variations were plotted in the figure. The four regions are I: the Hokkaido-Tohoku district; II: the Kanto-Tokai district; III: the Pacific coast of Kinki - Pacific coast of Kyushu district; and IV: the Hokuriku-East China Sea coast of Kyushu district.

The sea level variation in the graph is a time-series of the annual mean sea-level anomalies for each year, obtained using the 1971 to 2000 average as the normal. The solid blue line represents the five-year running mean of sea-level annual anomalies averaged among the four stations, while the solid red line represents this value for the four regions. The dashed blue line represents this value at the four stations 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 2007 is as high as 0.96. Accordingly, the extent to which changing the tide gauge stations used affects the 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 Geographical Survey Institute. Sea-level data for the Tokyo station are available from 1968 onward.
Figure 2.2.4 shows time-series representations of the mean value of annual mean sea-level anomalies after 1960 at the stations involved in each region, shown as I, II, III and IV on the map to the right of Figure 2.2.3. In recent years, the sea level reached its highest in 2004 before falling significantly in 2005 for each region. In 2006, the sea level fell in the region along the coast from Hokkaido to Tohoku and from Kanto to Tokai, while it rose in the other regions. In 2007, the sea level fell along the Pacific coast from Kinki to Kyushu, while it rose in the other regions. The average value over the four sea regions in 2009 was 15 mm higher than that in 2008. In terms of increase from the previous year by region, the largest increase was the value of 30 mm observed along the coast from Hokkaido to Tohoku (I), and the second largest was 16 mm from the coast of Hokuriku to the East China Sea coast of Kyushu (IV). This is attributed to an increase in subsurface temperatures in these regions from 2008. The corresponding increase was less than 10 mm along the Pacific coast from Kanto to Tokai (II) and from Kinki to Kyushu (III).

The significant variance of sea levels along the coast from Kanto to Tokai is mainly attributed to the influence of the Kuroshio meander seen from July 2004 to August 2005. When this meander occurred, a flow branching off from its main stream ran westward along the coast from Kanto to Tokai, and seawater was transported ashore under the influence of the earth’s rotation. As a result of the effect of this westward flow and thermal expansion in the seawater, the sea level for 2004 was the highest seen in the last ten years. A cold eddy formed in the northern area of the Kuroshio’s meander; as it ended and the westward flow disappeared in 2005, cold seawater covered the coast of these districts. As a result, the sea level along the coast from Kanto to Tokai fell after 2005, and in 2006 it was 116 mm lower than in 2004. However, in 2007, the influence of cold water along the coast of Tokai declined, and the sea level became 60 mm higher than in 2006. From 2007 to 2009, the Kuroshio maintained its non-meandering path, and no significant variance was seen in the annual mean sea level along the coast from Kanto to Tokai.

From 1960 to 2009, the increasing trend in the sea level from the coast of Hokuriku to the East China Sea coast of Kyushu was larger than that of the other regions.
Figure 2.2.4  Time-series representations of annual mean sea-level anomalies (1960 – 2009) for the four regions shown to the bottom right of Figure 2.2.3. These are I: the Hokkaido-Tohoku district; II: the Kanto-Tokai district; III: the Pacific coast of Kinki - Pacific coast of Kyushu district; and IV: the Hokuriku-East China Sea coast of Kyushu district. The average values for the four regions are also shown. The normal is the 1971 – 2000 average. Each line is shifted by 100 mm for clarity.

At a constant sea surface pressure, sea level varies with seawater density, which is affected by subsurface salinity as well as subsurface temperature. JMA has been conducting oceanographic observation using research vessels in the seas around Japan and in the western North Pacific since the 1960s. Based on the profiles of seawater temperature and salinity obtained, seawater density and sea surface dynamic height are calculated. Figure 2.2.5 shows temporal variations in the sea surface dynamic height at representative oceanographic observation points for (A) the East China Sea and (B) the sea south of Honshu, together with annual mean sea level anomalies measured at the tide gauge station nearest to each observation point. Both the yearly values and the trend in the long-term variation of dynamic height at oceanographic observation point A are similar to those of the sea level at Naha station. The sea level variation accompanying the subsurface seawater density changes in the sea near Naha is the main factor behind the sea level variation at the tide gauge along the coast. Meanwhile, the trend in the long-term variation of dynamic height at oceanographic observation point B is similar to that of the sea level at Chichijima station, though the yearly values of dynamic height show slight systematic differences from those of the sea level at Chichijima station.
Figure 2.2.5 Map showing the oceanographic observation points (A and B) and the nearest tide gauge stations of Naha and Chichijima (panel above), and time-series representations of anomalies in sea surface dynamic height at each oceanographic observation point and anomalies in sea level at the nearest tide gauge station (panels on the right). The periods of oceanographic observation are 1972 – 2009 at point A and 1976 – 2009 at point B. The anomaly in the sea surface dynamic height is shown as the deviation from the normal value, calculated using profiles of subsurface temperature and salinity. The blue lines represent variations in dynamic height at the oceanographic observation points, while the red ones indicate variations in sea level at the corresponding tide gauge stations. The normal values for the oceanographic observation points are the 1972 – 2000 average at A and the 1976 – 2000 average at B. The normal values for the tide gauge stations are the 1971 – 2000 average at Naha and the 1976 – 2000 average at Chichijima.
2.3 Sea ice in the Sea of Okhotsk

From December 2008 to May 2009, the sea ice extent in the Sea of Okhotsk was below normal (the 30-year average from 1970/1971 to 1999/2000) except in early March and late May (Figure 2.2.6). On March 5, the sea ice extent reached its seasonal maximum of $109.34 \times 10^4$ km$^2$. The previous seasonal maximum was $110.69 \times 10^4$ km$^2$ (Figure 2.2.7), and the normal is $122.83 \times 10^4$ km$^2$.

In December 2009, the sea ice extent in the Sea of Okhotsk was below normal except in early December (Figure 2.2.6).

Although the accumulated sea ice extent in the Sea of Okhotsk shows large interannual variations, a modest downward trend for the period from 1971 to 2009 is seen (Figure 2.2.7). The accumulated sea ice extent from December 2008 to May 2009 was the second lowest since statistics began in 1971 following the historical minimum of 2006.

The last date on which drift ice was visible from Abashiri (a city on the coast of Hokkaido facing the Sea of Okhotsk) was March 17, which was the earliest since 1946. The period between the first and last dates on which drift ice was visible was 43 days, which tied the record-short duration set in 1991. From Wakkanai, Kushiro and Nemuro, drift ice was not seen at all for the first time in two years. There have been four years in which drift ice has not been visible from Nemuro since 1990.

![Figure 2.2.6](image)

Figure 2.2.6  Seasonal variations of sea ice extent in the Sea of Okhotsk from December 2008 to May 2009 and December 2009. The normal is the 30-year mean from 1970/1971 to 1999/2000.
Figure 2.2.7  Time-series representations of maximum sea ice extent (red) and accumulated sea ice extent (green) values in the Sea of Okhotsk from 1971 to 2009. The term *accumulated sea ice extent* refers to the seasonal sum of sea ice extents at five-day intervals from December to May.
2.4 Marine pollution in the western North Pacific

Activities based on an international framework are essential in the prevention of marine pollution. In Japan, the Law Relating to the Prevention of Marine Pollution and Maritime Disaster took effect in 1971 against a background of discussion on the adoption of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter (a.k.a. the London Dumping Convention, or LDC) and the International Convention for the Prevention of Pollution from Ships (a.k.a. the MARPOL73/78 Convention). For the purposes of preventing marine pollution and preserving the marine environment based on this law, the Japan Meteorological Agency (JMA) has been monitoring background marine pollution since 1972.

2.4.1 Floating pollutants (plastics)

Floating pollutants are counted by observers from the bridges of research vessels during the daytime. When such pollutants are found, their location, shape classification, size, number of pieces and time of observation are recorded (“NIL” is noted if no pollutant is found). The data observed are arranged by adding together the numbers of floating pollutants counted along cruise tracks of 100 km each.

Figure 2.2.8 shows the distribution of floating plastic in the four seasons of 2009. A black circle with a size corresponding to the number of plastic pieces found is plotted on the ship’s position at noon of each day (“+” symbols denote “NIL”). Floating pollutant concentrations of more than 10 pieces/100 km were observed in some regions adjacent to Japan throughout all seasons. Especially in summer and autumn, large concentrations of more than 50 pieces/100 km were found. The concentration of floating pollutants recorded in the area south of 20°N was rarely more than 5 pieces/100 km, but reached more than 10 pieces/100 km in summer in the equatorial area.
Figure 2.2.8  Floating pollutants (plastics) observed in 2009 (a) winter, (b) spring, (c) summer and (d) autumn. “+” symbols denote that no pollutants were found during the daytime.
2.4.2 Floating tar balls (particulate petroleum residue)

Tar balls are the remnants of oil spills, and come from bilge water discharged by ships or crude oil stemming from sea disasters. They lose volatile components through the weathering process, and finally form ball-like shapes. Their diameter is usually between one and several millimeters, but they very occasionally also reach tens of centimeters. Floating tar balls are gathered using a neuston net (with a mouth width of 75 cm or 50 cm and a mesh size of 0.35 mm) that is fed out from the research vessel and towed 1.5 nautical miles (about 2.8 km). The tar ball density (in units of mg/m²) is then calculated by dividing the weight of the tar balls gathered by the area that the mouth of the neuston net has passed through. This information is then recorded along with other details of observation, including the station location and the time and date. (If no tar balls are gathered, “NIL” is recorded.)

The locations of tar ball observations in 2009 are shown in Figure 2.2.9. It can be seen that none were collected in any of the observation areas. Since 1996, tar balls have rarely been collected in the western North Pacific.
Figure 2.2.9  Distribution of floating tar balls in 2009 (a) winter, (b) spring, (c) summer and (d) autumn. “+” symbols denote that no tar was collected.

2.4.3  Heavy metals

Heavy metals are a group of elements that have specific gravities of greater than 4 – 5. Although living organisms require many kinds of heavy metal, some of them are detrimental to the body. JMA sets mercury and cadmium as monitoring items, as they tend to accumulate in organisms and can cause serious injury.
Table 2.2.1 shows the concentrations of mercury and cadmium in surface seawater observed in 2009 (the observation stations are shown in Figure 2.2.10).

The highest concentration of mercury was 24 ng/kg, observed at the station located at 30°N, 137°E. This concentration is lower than 1/20 of the environmental quality standards value for public water areas provided by the Environmental Quality Standards for Water Pollution (Bulletin No. 59, 1971, Environmental Agency). The highest concentration of cadmium, 64 ng/kg, was observed in the area south of Hokkaido. This is lower than 1/150 of the above environmental quality standards value. The concentrations of mercury and cadmium were therefore within the limits of a natural background level.

It is well known that cadmium concentration in seawater shows a high correlation with phosphate concentration, and that their vertical profiles are similar. Since the area south of Hokkaido roughly corresponds to the Oyashio area, which is abundant in nutrients such as phosphates, higher concentrations of cadmium can be detected than in the area south of Honshu. This region roughly corresponds to the Kuroshio area, which is not abundant in nutrient salts.

Table 2.2.1 Concentrations of mercury and cadmium in surface seawater observed in 2009
* Environmental quality standards value, converted into ng/kg units (provided by Environmental Quality Standards for Water Pollution (Bulletin No. 59, 1971, Environmental Agency))

<table>
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<tr>
<th>Area</th>
<th>Mercury</th>
<th>Cadmium</th>
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<tr>
<td>South of Hokkaido</td>
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<td>15 – 64</td>
</tr>
<tr>
<td>Sea of Japan</td>
<td>1 – 3</td>
<td>7 – 33</td>
</tr>
<tr>
<td>Off the Boso Peninsula</td>
<td>2 – 21</td>
<td>1 – 25</td>
</tr>
<tr>
<td>South of Honshu</td>
<td>0 – 2</td>
<td>0 – 9</td>
</tr>
<tr>
<td>East China Sea</td>
<td>0 – 7</td>
<td>0 – 12</td>
</tr>
<tr>
<td>Western North Pacific</td>
<td></td>
<td></td>
</tr>
<tr>
<td>137°E line 20°N – 30°N</td>
<td>1 – 24</td>
<td>0 – 1</td>
</tr>
<tr>
<td>137°E line 5°N – 15°N</td>
<td>2 – 7</td>
<td>0 – 4</td>
</tr>
<tr>
<td>Environmental quality standards *</td>
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<td>10,000</td>
</tr>
</tbody>
</table>

Figure 2.2.10 Observation stations for heavy metals (mercury and cadmium). The red circles denote observation stations in the seas adjacent to Japan, and the red line denotes the 137°E meridian on which observation stations are set at 5° intervals of latitude.
Part III  Atmospheric Environment

Environmental policies should be based on a scientific understanding of the current state of our environment and its changes. To this end, JMA conducts observations on the atmospheric environment as part of worldwide observation networks such as WMO’s Global Atmosphere Watch (GAW) programme.

Section 1 of this part outlines the results of observation on greenhouse gases, ozone-depleting substances and aerosols. Surface concentrations of carbon dioxide (CO$_2$) and methane (CH$_4$) are observed at three stations in Japan, and their concentrations in the upper troposphere (at altitudes of 8 – 13 km) are observed using commercial passenger aircraft. Their concentrations in the air and the seawater of the western North Pacific are also observed using research vessels. Noting the effects of these gases on the global climate, atmospheric turbidity is observed from direct solar radiation measurements at four stations, and aerosol optical depths are recorded at three stations in Japan.

Section 2 deals with the results of observation on the ozone layer and UV. The details are also available in the Annual Report of Ozone Layer Monitoring: 2009.

Section 3 covers the results of observation on Kosa (Aeolian dust) and acid rain.

Figure 3.1.1 shows the locations of the measurement stations for greenhouse gases, direct solar radiation, the ozone layer and UV, and acid rain. Kosa is observed at 67 stations in Japan, but these are not shown in the figure.

JMA operates the WMO World Data Centre for Greenhouse Gases (WDCGG) to collect, archive and provide data on greenhouse gases throughout the world. The archived data can be accessed globally through the Internet (http://gaw.kishou.go.jp/wdcgg/wdcgg.html), enabling their use in various studies on the carbon cycle among the atmosphere, the ocean and the biosphere, as well as those on projections of global warming.

![Map of observation stations](image)

Figure 3.1.1  Map of observation stations for greenhouse gases (three stations), direct solar radiation (four stations), the ozone layer and UV radiation (four stations) and precipitation chemistry (two stations)
1 Monitoring of greenhouse gases and ozone-depleting substances

1.1 Greenhouse gases and ozone-depleting substances in the atmosphere

Table 3.1.1 shows the global concentrations of greenhouse gases analyzed from data reported to the WDCGG up until 2009. Global mean atmospheric concentrations of carbon dioxide (CO₂) and nitrous oxide (N₂O) continue to rise. The year-on-year increase in the global mean concentration of methane (CH₄) in 2008 was 7 ppb – the same as the value for 2007. The global mean concentration of carbon monoxide (CO, which itself is not a greenhouse gas but affects the concentrations of greenhouse gases through various chemical reactions) shows no significant trend.

Table 3.1.1 Global mean concentrations of greenhouse gases

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Atmospheric concentration</th>
<th>Increase from previous year</th>
<th>Property</th>
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<td>Pre-industrial level</td>
<td>Global mean in 2008</td>
<td>Life time (in years)</td>
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<td></td>
<td></td>
<td>(growth rate from</td>
<td>Lifetime (in years)</td>
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<tr>
<td></td>
<td></td>
<td>pre-industrial level)</td>
<td>Lifetime (in years)</td>
</tr>
<tr>
<td>CO₂</td>
<td>About 280 ppm</td>
<td>385.2 ppm (+38%)</td>
<td>-</td>
</tr>
<tr>
<td>CH₄</td>
<td>About 715 ppb</td>
<td>1,797 ppb (+151%)</td>
<td>+7 ppb</td>
</tr>
<tr>
<td>N₂O</td>
<td>About 270 ppb</td>
<td>321.8 ppb (+19%)</td>
<td>+0.9 ppb</td>
</tr>
<tr>
<td>CO</td>
<td>About 91 ppb</td>
<td>−4 ppb</td>
<td>About 0.25</td>
</tr>
</tbody>
</table>

* Radiative forcing is a measure of the influence that a factor exerts in altering the balance of incoming and outgoing energy in the earth-atmosphere system, and is an index of the importance of the factor as a potential climate change mechanism. It is expressed in Watts per square meter (W/m²).

1.1.1 Carbon Dioxide

Of all the greenhouse gases, CO₂ is the most significant contributor to global warming. Since the start of the industrial era in the late 18th century, the atmospheric concentration of CO₂ has been increasing as a result of emissions from various human activities such as fossil fuel combustion, cement production and deforestation. Among these activities, the combustion of fossil fuels accounts for about three quarters of all anthropogenic CO₂ emissions.

Figure 3.1.2 shows time-series representations of atmospheric CO₂ concentrations at Ryori (Ofunato City, Iwate, Japan), Mauna Loa (Hawaii, USA) and the South Pole. These concentrations have been observed since 1957 at the South Pole, since 1958 at Mauna Loa and since 1987 at Ryori. The concentrations at the South Pole and Mauna Loa were about 315 ppm at the beginning of the observation period, and have been increasing gradually with seasonal variations. The WDCGG’s analysis indicates that the globally averaged annual mean concentration of CO₂ in the atmosphere was 385.2 ppm in 2008 – a 2.0-ppm increase from 2007. This is 38% higher than the prevailing level before the industrial era (280 ppm). The analyzed annual increase of 2.0 ppm up to 2008 is larger than the average growth rate for the
1990s (1.5 ppm/year). In addition, the average growth rate over the last decade (1.9 ppm/year) is larger than that seen over the 1990s. This is largely attributable to increased CO$_2$ emissions from fossil fuel combustion.

Figure 3.1.2 Time-series representations of monthly mean atmospheric CO$_2$ concentrations at Ryori (Japan), Mauna Loa (Hawaii, USA) and the South Pole based on data from the WDCGG and the Carbon Dioxide Information Analysis Center in the USA.

Figure 3.1.3 Three-dimensional representations of monthly variations in zonally averaged atmospheric CO$_2$ concentrations (top) and growth rates (bottom). This analysis was performed using data archived by the WDCGG.
Figure 3.1.3 shows variations in zonally averaged atmospheric CO₂ concentrations (top) and growth rates (bottom) produced by the WDCGG using archived data from all over the world. The concentrations are high in the mid and high latitudes in the Northern Hemisphere, and decrease toward the southerly latitudes. This latitudinal distribution of CO₂ concentration is ascribed to the existence of major CO₂ sources in the mid and high latitudes of the Northern Hemisphere. The seasonal variation (a decrease from spring to summer and an increase from summer to the following spring) is mainly due to the activity of the terrestrial biosphere (photosynthesis and decomposition of soil organic matter), and the amplitude is smaller in the Southern Hemisphere because of the small land area. In both hemispheres, atmospheric CO₂ concentrations are increasing year by year. The global mean growth rate during the 1983 – 2008 period was 1.7 ppm/year.

Figure 3.1.4 shows monthly mean atmospheric CO₂ concentrations, deseasonalized trends (a) and growth rates (b) at Ryori, Minamitorishima and Yonagunijima. The deseasonalized trends are obtained by filtering out variations associated with the seasonal cycle and shorter variations. At all stations, CO₂ concentrations increase with seasonal variations in relation to photosynthesis and respiration in the biosphere. The CO₂ concentration at Ryori has a larger seasonal variation than the other two stations because of its location at a high latitude, where the atmosphere is significantly influenced by biospheric activity. The CO₂ concentrations are generally higher at Yonagunijima (in the Nansei Islands) than at Minamitorishima (in the Ogasawara Islands) despite the almost identical latitudes of the two locations. This reflects the influence of anthropogenic and wintertime biospheric emissions from the Asian continent.

The annual mean CO₂ concentrations in 2009 were 389.7 ppm at Ryori, 388.0 ppm at Minamitorishima and 389.4 ppm at Yonagunijima, representing changes over the previous year of +1.2 ppm, +1.4 ppm and +1.4 ppm respectively, and were the highest on record.

Figure 3.1.4 Time-series representations of monthly mean atmospheric CO₂ concentrations, deseasonalized concentrations (a) and growth rates (b) at Ryori, Minamitorishima and Yonagunijima
The Meteorological Research Institute and the National Institute for Environmental Studies carry out measurement of greenhouse gases such as CO₂ at altitudes of 8 – 13 km using commercial passenger aircraft between Japan and Australia in cooperation with the JAL Foundation, the Ministry of Land, Infrastructure, Transport and Tourism, and Japan Airlines. Figure 3.1.5 shows time-series representations of atmospheric CO₂ concentrations and growth rates averaged zonally for every five degrees of latitude from 30°N to 25°S. CO₂ levels continuously increase at all latitudes – a trend also seen in surface measurements (Figure 3.1.4) – but the amplitude of the seasonal cycles is smaller than that of surface measurements. The CO₂ variations in the Southern Hemisphere are more complicated than those in the Northern Hemisphere, and include double-peak seasonality in some cases.

The growth rates of CO₂ concentrations have varied significantly year by year. Figure 3.1.3 shows globally higher rates in 1983, 1987 – 1988, 1994 – 1995, 1997 – 1998, 2002 – 2003 and 2005, and significantly decreased levels for 1992 – 1993 when negative growth rates were observed in northern high latitudes. Such interannual variations in CO₂ growth rates were also observed at three Japanese ground-based stations (as shown in Figure 3.1.4) and in the upper troposphere over the Pacific Ocean (as shown in Figure 3.1.5).

The increases in the CO₂ growth rate from 1997 to 1998 and from 2002 to 2003, as well as
the subsequent decreases, are related to El Niño events in 1997/1998 and 2002/2003 respectively. El Niño events have two opposite effects on the atmospheric concentration of CO₂. On one hand, the suppressed upwelling of CO₂-rich ocean water reduces CO₂ emissions from the ocean into the atmosphere in the eastern equatorial Pacific. On the other hand, warmer and drier weather strengthens CO₂ emissions from the terrestrial biosphere (particularly in tropical regions) through strengthened plant respiration and organic soil decomposition as well as depressed photosynthesis. In total, the latter effect exceeds the former, which brings about a net CO₂ increase in the atmosphere with a lag of several months. The anomalously low precipitation in 1997/1998 (which brought droughts and frequent forest fires in Southeast Asia) and the remarkably high global mean temperature in 1998 are considered to have strengthened CO₂ emissions from the terrestrial biosphere.

Despite the 1991/1992 El Niño event, the CO₂ growth rate decreased significantly during 1992 – 1993. Global cooling caused by the eruption of Mt. Pinatubo in June 1991 brought about reduced CO₂ emissions from terrestrial respiration and strengthened CO₂ absorption into the ocean. The high growth rates seen in 2005 – 2006 (despite the occurrence of a La Niña event rather than El Niño in the tropical ocean) may be related to increased CO₂ emissions from fossil fuel combustion and the global high temperature, with the highest hemispheric mean temperature being recorded in 2005 and the third highest in 2006 in the Northern Hemisphere.

These interannual changes in the CO₂ growth rate can be attributed to fluctuations in the carbon cycle due to climatic variations. Moreover, fluctuations in this cycle affect the climate through the greenhouse effect; the mechanism of the carbon cycle system, including its interannual variations, should therefore be clarified to improve the projection of global warming.
1.1.2 Methane

Methane (CH\textsubscript{4}) is the second most significant greenhouse gas after CO\textsubscript{2}, and is emitted into the atmosphere from various sources including wetlands, rice paddy fields, ruminant animals, natural gas production and biomass burning. CH\textsubscript{4} is primarily removed from the atmosphere by photochemical reaction with reactive and unstable hydroxyl (OH) radicals, and has a lifetime of nine years. Its atmospheric concentrations have shown a long-term increase since the early 19th century. The WDCGG’s analysis indicates that the globally averaged atmospheric CH\textsubscript{4} concentration in 2008 was 1,797 ppb (a 7-ppb increase on the previous year), which was the highest value recorded since 1984. The annual CH\textsubscript{4} concentration increase in 2008 was as high as that for the previous year. This is 151% higher than the prevailing level seen before the 18th century (715 ppb).

Figure 3.1.6 shows variations in zonally averaged atmospheric CH\textsubscript{4} concentrations from 1984 to 2008 produced by the WDCGG using archived data from all over the world. The concentrations decline southward from mid and high latitudes in the Northern Hemisphere. This is because sources of CH\textsubscript{4} are mainly land-based, and the Northern Hemisphere has a larger area of land than the Southern Hemisphere.

![Figure 3.1.6](image-url)  
Figure 3.1.6 Three-dimensional representations of monthly variations in zonally averaged atmospheric CH\textsubscript{4} concentrations (top) and growth rates (bottom). This analysis was performed using data archived by the WDCGG.
Generally, growth rates were lower in the 1990s than in the 1980s, when global mean CH₄ concentrations were increasing in line with growing emissions from anthropogenic sources such as agricultural and industrial activity. However, the situation may be in transition to a steady state in which the removal of CH₄ is balanced with emissions from its sources. The mechanism has not yet been fully elucidated, and it is uncertain whether the increases of CH₄ observed in 2007 and 2008 will continue or not in the future. It is necessary to monitor the situation closely.

Figure 3.1.7 shows monthly mean concentrations, deseasonalized trends and growth rates for atmospheric CH₄ at Ryori, Minamitorishima and Yonagunijima.

The annual mean CH₄ concentrations in 2009 were 1,878 ppb at Ryori, 1,822 ppb at Minamitorishima and 1,851 ppb at Yonagunijima, representing changes over the previous year of +2 ppb, +8 ppb and +11 ppb respectively. The annual mean concentrations in 2009 reached their highest levels at all three stations.

![Graphs showing CH₄ concentrations and growth rates](image)

Figure 3.1.7 Time-series representations of monthly mean concentrations with deseasonalized trends (top) and growth rates (bottom) for atmospheric CH₄ at Ryori, Minamitorishima and Yonagunijima.
1.1.3 Nitrous Oxide

Nitrous oxide (N$_2$O) is a significant greenhouse gas because of its radiative effect per unit mass (about 300 times greater than that of CO$_2$) and its long lifetime (about 114 years) in the atmosphere. N$_2$O is emitted into the atmosphere by soil, the ocean, the use of nitrate and ammonium fertilizers, and various industrial processes. It is photodissociated in the stratosphere by ultraviolet radiation.

Concentrations of atmospheric N$_2$O have been increasing slightly on a global scale. The WDCGG’s analysis indicates that the global mean concentration of atmospheric N$_2$O was 321.8 ppb in 2008. This is 19% higher than the value considered to be the prevailing concentration before the 18th century (270 ppb).

Figure 3.1.8 shows a time-series representation of monthly mean N$_2$O concentrations in the atmosphere observed at Ryori. Short-term variations are weak, and no seasonal variability is observed. The annual mean N$_2$O concentration was 323.9 ppb in 2009, showing a continuation of the slightly increasing trend. The observation system was replaced at the beginning of 2004 and 2008.

![Monthly mean N$_2$O concentration](image)

Figure 3.1.8 Time-series representation of monthly mean atmospheric N$_2$O concentrations at Ryori

1.1.4 Halocarbons

Halocarbons are carbonic compounds with fluorine, chlorine, bromine or iodine. Most are chemically manufactured rather than being formed naturally in the atmosphere. They not only destroy stratospheric ozone, but also warm the global atmosphere directly as greenhouse gases, and at the same time cool the lower stratosphere indirectly as a result of this stratospheric ozone destruction. Most halocarbons have atmospheric concentrations less than a millionth of CO$_2$ levels. However, they contribute significantly to global warming because of their radiative effects per unit mass, which are several thousand times greater than that of CO$_2$. Furthermore, these effects last a very long time because of the extended lifetime of halocarbons in the atmosphere.

Chlorofluorocarbons (CFCs), which are compounds of carbon, fluorine and chlorine, are important halocarbons. CFC emissions are regulated under the Montreal Protocol on Substances that Deplete the Ozone Layer and its Amendments and Adjustments. Consequently, observation data collected from all over the world by the WDCGG show that CFC-11 concentration peaked in 1993 and has declined since then. The increasing tendency of
CFC-12 concentration has slowed since 1996, and has remained almost unchanged in recent years. The concentration of CFC-113 had stopped increasing by 1996, and has decreased gradually since then.

Figure 3.1.9 shows a time-series representation of monthly mean concentrations of CFC-11, CFC-12 and CFC-113 in the atmosphere observed at Ryori, indicating weak short-term variations and an absence of seasonal variability. As seen in other observations globally, the concentration of CFC-11 peaked at about 270 ppt in 1993 – 1994, and has decreased since then. The CFC-12 concentration increased until 1995 and continued to rise slowly until 2005, but has been decreasing gradually since then. The concentration of CFC-113 had stopped increasing by 2001 and decreased slowly thereafter, but has remained almost unchanged in recent years. The annual mean concentrations in 2009 were 246 ppt for CFC-11, 537 ppt for CFC-12 and 78 ppt for CFC-113.

Concentrations of hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), used as substitutes for CFCs, have been increasing in the atmosphere. As an example, the Special Report on Safeguarding the Ozone Layer and the Global Climate System by the Intergovernmental Panel on Climate Change (IPCC) and the Technology and Economic Assessment Panel (TEAP) reported that HCFCs are increasing by 3 – 7% per year and HFCs by 13 – 17% per year. In addition, WMO Greenhouse Gas Bulletin No. 5 reported that the concentration of sulphur hexafluoride (SF₆), which is used as an electrical insulator in power distribution, had increased to twice the levels seen in the mid-1990s by 2008. HFCs, PFCs and SF₆ were not subject to controls when the Montreal Protocol was adopted, but now they (together with CO₂, CH₄ and N₂O) are greenhouse gases covered by the Kyoto Protocol to the United Nations Framework Convention on Climate Change.
Figure 3.1.9  Time-series representations of monthly mean concentrations of atmospheric CFC-11 (top), CFC-12 (middle) and CFC-113 (bottom) at Ryori
1.1.5 Carbon Monoxide

Sources of carbon monoxide (CO) include the combustion of fossil fuels and biomass and the oxidation of methane and other hydrocarbons. It is removed mainly through reaction with OH radicals in the atmosphere. CO in the atmosphere has a lifetime of 2 – 3 months and depends on local emissions, resulting in large spatial and temporal variations. CO is not a greenhouse gas in itself because it hardly absorbs infrared radiation from the earth’s surface. However, it is a precursor of tropospheric ozone, and controls the concentrations of many greenhouse gases through reaction with OH radicals.

The WDCGG’s analysis indicates that the globally averaged atmospheric CO concentration in 2008 was about 91 ppb. Ice-core analysis shows that the concentration of CO in Antarctica has remained at approximately 50 ppb with little change over the last 2,000 years. The results also suggest that the concentration of CO in Greenland was about 90 ppb before the middle of the 19th century, and had increased gradually to about 110 ppb by 1950.

Figure 3.1.10 shows annual variations in the latitudinal distribution of CO concentration and its growth rate for the period 1992 – 2008. There is a clear seasonal cycle of high concentrations from winter to spring and low concentrations in summer because more CO is removed through the active chemical reaction of OH radicals during the summer months. The levels are high in northern mid and high latitudes and low in the Southern Hemisphere, indicating that the major sources are in the northern mid and high latitudes, and that the concentration decreases toward tropical ocean areas where CO is destroyed photochemically.

Concentrations from the equatorial area to the northern mid and high latitudes increased from 1997 to 1998. The large-scale biomass burning in Indonesia in 1997 and forest fires in Siberia from summer to autumn in 1998 influenced the increase in CO levels. Concentrations from equatorial areas to northern mid and high latitudes also increased from 2002 to 2003 for the same reason.

Figure 3.1.11 shows a time-series representation of monthly mean concentrations and deseasonalized trends for atmospheric CO at Ryori, Minamitorishima and Yonagunijima. The concentrations show seasonal variations with a peak from winter to early spring and a depression in summer. An increase in CO concentration was seen from 1997 to 1998, suggesting an influence from the forest fires in Indonesia and Siberia. A smaller increase was also seen from 2002 to 2003. The annual mean concentrations in 2009 were 146 ppb at Ryori and 105 ppb at Minamitorishima, representing changes over the previous year of -22 ppb and -1 ppb respectively. The annual mean concentration in 2008 was 144 ppb at Yonagunijima, where the observation system was replaced in January 2008. The extent to which this figure was influenced by the replacement is now under investigation.

The eastern part of the Asian continent is considered to have one of the highest levels of CO emission due to the active consumption of fossil fuels in the region. Recent analysis suggests that the amount of CO discharged from this area accounts for a third of the world’s total. The concentration at Yonagunijima is higher than that at Minamitorishima, despite their almost identical latitudes, because the former is more strongly influenced by CO emissions from the Asian continent. The high CO concentrations seen at Yonagunijima in the first halves of the years since 2003 are also thought to have been influenced by exposure to airflow from the Asian continent.
Figure 3.1.10  Three-dimensional representations of monthly variations in zonally averaged atmospheric CO concentrations (top) and growth rates (bottom). This analysis was performed using data archived by the WDCGG.

Figure 3.1.11  Time-series representations of monthly mean concentrations and deseasonalized trends for atmospheric CO at Ryori, Minamitorishima and Yonagunijima. Data for Minamitorishima from January 2004 to October 2006 are missing due to equipment problems and typhoon damage. Observation data at Yonagunijima have been indicated by open circles since January 2008 when the observation system was replaced. The extent to which the replacement has influenced measurements is now under investigation.
1.1.6 Tropospheric Ozone

Atmospheric ozone ($O_3$) is found mostly in the stratosphere, and shields life on earth by absorbing harmful ultraviolet solar radiation. Tropospheric $O_3$ accounts for under 10% in terms of mass, but in high concentrations can cause harm to humans (such as eye or throat irritation) and plants. In Japan, its concentration is therefore regulated to an hourly mean of below 60 ppb. Tropospheric $O_3$ acts as a significant greenhouse gas because it also has strong absorption bands in the infrared and ultraviolet wavelength ranges. It is also a chemically reactive gas, and produces OH radicals that control the atmospheric concentrations of many greenhouse gases (such as CH$_4$) through chemical reactions.

Tropospheric $O_3$ is transported from the stratosphere or produced by photochemical processes between CO, hydrocarbons (NMHCs), nitrogen oxides (NOx) and other substances that are emitted from the transport and industry sectors. $O_3$ is removed through reaction with hydrogen oxides (HOx, i.e. HO$_2$ and OH). In mid and high latitudes, $O_3$ is transported from the stratosphere down to the troposphere, and is destroyed on the earth’s surface. As its concentration varies significantly with location, altitude and season, observation must be made in rural areas away from urban centers in order to monitor long-term variations free from the influence of human activities.

Figure 3.1.12 shows a time-series representation of monthly mean concentrations and deseasonalized trends for surface $O_3$ at Ryori, Minamitorishima and Yonagunijima. The levels usually show seasonal variations with a peak in winter or spring and a depression in summer. This summer change is attributed to increased OH radical concentrations (which reduce the concentration of $O_3$) as water vapor increases with rising temperatures. While Yonagunijima is located in the same latitudinal zone as Minamitorishima, the concentration is usually higher at the former than at the latter. In the eastern part of China, the peak monthly mean ozone concentration is observed in autumn, and the maximum exceeds 60 ppb at the Changjiang River Delta. The values recorded at Yonagunijima are higher than those at Ryori from autumn to early spring; this is thought to be a result of ozone-rich air masses being transported from the Asian continent to Yonagunijima.

The high concentrations seen at Yonagunijima and Ryori in the spring of 2003, 2004 and 2005 were also influenced by air masses from the Asian continent. The annual mean concentrations in 2009 were 41 ppb at Ryori, 24 ppb at Minamitorishima and 39 ppb at Yonagunijima, representing changes over the previous year of +2 ppb, −2 ppb and +1 ppb respectively. At Minamitorishima, the annual mean concentration in 2009 reached its lowest level since observation started in 1994.
1.2 Oceanic carbon dioxide

Improved projection of atmospheric CO₂ concentration and global warming requires accurate quantification of the amount of anthropogenically released CO₂ taken up by the ocean. On a global scale, it is estimated that the ocean absorbs CO₂ at a rate of about 2.2 PgC \( (2.2 \times 10^{15} \text{ grams of carbon}) \) per year (IPCC, 2007). On a regional scale, however, the amount of oceanic CO₂ absorption changes from place to place. Some areas (such as the equatorial Pacific) emit CO₂, while the role of other regions as a sink or source of atmospheric CO₂ changes from season to season. This geographical heterogeneity and seasonal changes in the amount of oceanic CO₂ absorption make it difficult to estimate oceanic CO₂ uptake as a whole. It is necessary to evaluate the absorption or emission of CO₂ quantitatively for each region and season in order to reduce the uncertainty of estimates. To this end, JMA conducts marine observations of CO₂ in the air and seawater of the western North Pacific using the research vessels Ryofu Maru and Keifu Maru (see the panel on the left of Figure 3.1.13). CO₂ concentrations in the air and seawater are measured continuously using an automated system installed in the laboratories of these vessels. The panel on the right of Figure 3.1.13 shows the distributions of the partial pressure difference in CO₂ \( (\Delta p\text{CO}_2) \) between the surface seawater and the air above it as observed by the Ryofu Maru and Keifu Maru in the winter (January – March), spring (April – May), summer (June – August) and autumn (October – November) of 2009. Oceanic and atmospheric CO₂ partial pressures are calculated using each value for CO₂ concentration (i.e. mole fraction), barometric pressure and saturated vapor pressure. A positive \( \Delta p\text{CO}_2 \) value means that the emission of CO₂ from the ocean to the atmosphere exceeds the absorption, and vice versa for a negative value. CO₂ absorption is predominant over the region observed by JMA vessels, except for equatorial regions in winter and south of Japan in summer and autumn where CO₂ emission dominates.
Figure 3.1.13  Left panel: The observation lines followed by JMA research vessels. Right panel: The results of surface observation of CO₂ in 2009. The columns show the partial pressure difference in CO₂ (ΔpCO₂) between the surface seawater and the air above it as observed by the Ryofu Maru and Keifu Maru in winter (upper left), spring (upper right), summer (lower left) and autumn (lower right) of 2009, in units of μatm.

Figure 3.1.14 shows a time-series representation of oceanic and atmospheric CO₂ concentrations averaged between 7°N and 33°N along 137°E (the red line in the panel on the left of Figure 3.1.13) for January and February. In this region, the concentrations of oceanic CO₂ are lower than those of atmospheric CO₂, suggesting that the ocean acts as a sink for atmospheric CO₂ in winter. The mean growth rates in atmospheric and oceanic CO₂ concentration from 1984 to 2009 are 1.7±0.1 ppm/year and 1.5±0.2 ppm/year respectively (the range indicated by the symbol ‘±’ represents a confidence level of 95%).

Figure 3.1.14  Time-series representations of oceanic (blue line) and atmospheric (red line) CO₂ concentrations averaged between 7°N and 33°N along 137°E in winter (January – February) from 1984 to 2009.
Figure 3.1.15 shows a time-series representation of oceanic and atmospheric CO₂ concentrations averaged between 156°E and 165°E along the equator (the blue line in the panel on the left of Figure 3.1.13) from 1996 to 2009. Usually, the oceanic CO₂ concentration in the eastern equatorial Pacific is higher than that in the western equatorial Pacific because of the equatorial upwelling of CO₂-rich water in the former. The variability of oceanic CO₂ concentration in the western equatorial Pacific is caused by east-west shifts of the boundary between the upwelling CO₂-rich region and the CO₂-poor warm water region. During the La Niña event from spring 2007 to spring 2008, CO₂-rich surface water covered the western equatorial region. After the end of the event in spring 2008, oceanic CO₂ concentration in the western equatorial Pacific remained high until the winter of 2009 because the trade winds were still strong in western and central Pacific areas. Oceanic CO₂ decreased to the level of atmospheric CO₂ in the summer of 2009. It is suggested that the boundary shifted eastward during this period.

![Image](image.png)

Figure 3.1.15 Time-series representations of oceanic and atmospheric CO₂ concentrations along the equator from 1996 to 2009. The concentrations are averaged between 156°E and 165°E except for 2009 (159.5°E and 165°E), for which the dots are underlined. The red and blue belts represent periods of El Niño and La Niña events respectively.

In the subtropical western North Pacific, a close correlation has been found between the oceanic CO₂ concentration in the surface layer and the sea surface temperature, based on observations along the 137°E line and the 165°E line (Inoue et al., 1995). Using this correlation and the observed atmospheric CO₂ concentration, JMA estimates oceanic CO₂ concentrations for the seasons and regions where no observed CO₂ data are available, and then calculates the air-sea partial pressure difference in CO₂. Furthermore, the air-sea CO₂ flux can also be estimated using the calculated oceanic CO₂ concentration and gas-transfer coefficients calculated from monthly mean sea surface wind speeds. Figure 3.1.16 shows seasonal and interannual variations in the oceanic CO₂ uptake from 1996 to 2008 in the
subtropical western North Pacific (11°N – 30°N and 130°E – 165°E), which occupies 2.6% of the global ocean. A positive value means that the emission of CO₂ from the ocean to the atmosphere exceeds the absorption, and vice versa for a negative value. This region acts as a source of atmospheric CO₂ in summer and a sink in winter. Over the year, however, the region acts as a net sink because the uptake in winter is estimated to be greater than the release in summer. The estimated annual oceanic CO₂ uptake fluctuated between 0.027 and 0.083 PgC (the average is 0.063 PgC) during the period, and was 0.061 PgC in 2008. The average uptake is about 2.8% of the global oceanic uptake (2.2 PgC for the average from 2000 to 2005, IPCC (2007)).

Figure 3.1.16  Net air-sea CO₂ exchange integrated (a) monthly and (b) yearly in the subtropical region of the western North Pacific (11°N – 30°N and 130°E – 165°E, from 1996 to 2008). The unit is PgC, representing petagrams (10¹⁵ grams) of carbon; positive values signify a flux into the atmosphere. The data used here are atmospheric CO₂ concentrations observed at Minamitorishima and monthly mean values of surface wind speed and sea surface temperature estimated from JMA objective-analysis data. The gas transfer coefficients were calculated using the equation given by Wanninkhof (1992) for the long-term average wind speed.
1.3 Aerosols

Small particles floating in the atmosphere are called aerosols. They affect the climate both directly and indirectly. Directly, most aerosols contribute to a decrease in the global temperature by scattering solar radiation, while they warm the atmosphere by absorbing and re-emitting infrared radiation from the earth’s surface. Escalating amounts of light-absorbing soot (black carbon) in the atmosphere also lead to an increase in the global temperature. Indirectly, aerosols change the characteristics of clouds by acting as cloud condensation nuclei (CCN), resulting in a change in the planetary albedo and thus an influence on the climate. While large uncertainties remain in terms of the contribution of such cooling and warming effects on the atmosphere, an increase in the amount of aerosols is estimated to cause a net decrease in the surface temperature on a global scale.

1.3.1 Interannual variation in the turbidity coefficient

JMA monitors direct solar radiation at four stations in Japan. The values obtained are used to calculate the Feussner-Dubois turbidity coefficient, which is an index of atmospheric loading for turbid constituents such as aerosols, water vapor, ozone and CO₂. The turbidity coefficient is expressed as the ratio of observed solar radiation extinction to that in an ideally pure atmosphere. Larger values therefore indicate higher levels of turbid constituents in the atmosphere.

Figure 3.1.17  Time-series representation of the Feussner-Dubois turbidity coefficient from 1960 to 2009 averaged over the whole of Japan. The monthly minimums are averaged to avoid the influence of water vapor and severe dust events.

Figure 3.1.17 shows interannual variations in the Feussner-Dubois turbidity coefficient from 1960 to 2009 with seasonal and short-term variations filtered out. In this analysis, the monthly minimum values are averaged over the whole of Japan to cancel out short-term variations from water vapor and severe dust events. The increased turbidity coefficients during the periods of 1963 – 1969, 1982 – 1985 and 1991 – 1993 were caused by the eruptions of Mt. Agung (Indonesia) in 1963, Mt. El Chichón (Mexico) in 1982 and Mt. Pinatubo (the Philippines) in 1991 respectively. These eruptions spewed huge amounts of SO₂ into the stratosphere, and this gas subsequently became sulfate aerosol. The turbidity
coefficient has now returned to approximately the level seen before the eruption of Mt. Agung
because no large-scale eruptions have occurred since that of Mt. Pinatubo.

1.3.2 Aerosol optical depth

JMA monitors aerosol optical depth (AOD) at three stations in Japan (Ryori, Minamitorishima and Yonagunijima) using sun photometers. Figure 3.1.18 shows monthly mean values of AOD observed at each station from 1998 to 2009.

At Ryori, AOD values usually reach their maximum in spring and their minimum in winter. The maximum value in spring may be attributed to Kosa (Aeolian dust) and air pollutants transported from the Asian continent. Some literature suggests that the effects of Kosa and continental pollutants on aerosol optical properties are comparable. The AOD value for May 2003 was about twice as high as normal because of smoke from forest fires in Siberia. This event is explained in detail in Climate Change Monitoring Report 2003. The high AOD value recorded in spring 2006 highlights the influence of large-scale Kosa events.

Minamitorishima shows lower AOD values than the other two stations throughout the year because its location is remote from the Asian continent, which is a source of land-originated aerosols. However, the average value recorded at Minamitorishima in spring, when the influence of the Asian continent is higher than in other seasons, far exceeds the yearly average for Hawaii. This suggests an influence from the long-distance transportation of Kosa and air pollutants. The difference in AOD values between 500 nm and 862 nm is smaller at Minamitorishima than at Ryori and Yonagunijima, suggesting that relatively large sea salt aerosols are more dominant at Minamitorishima than at the other two stations. AOD values at Minamitorishima reach their maximum in spring and their minimum in autumn.

At Yonagunijima, AOD values reach their maximum in spring and their minimum from summer to autumn. The reason for the former is similar to that for Ryori, where Kosa, air pollutants and smoke from forest fires are transported from the Asian continent, although the level of turbidity at Yonagunijima is higher than that at Ryori.
Figure 3.1.18  Time-series representations of monthly mean AOD at 500 nm and 862 nm from 1998 to 2009, observed at Ryori (top), Minamitoriishima (middle) and Yonagunijima (bottom). The values were calculated from thrice-daily observations until March 2007 and from continuous observation thereafter.
1.3.3 Vertical profiles of aerosols

Lidar (laser radar) is a remote sensing technology used to monitor vertical profiles of aerosol concentration by shooting a laser light upward, then detecting and analyzing the light scattered back by the atmosphere or aerosols. It can also distinguish spherical aerosols, such as the sulfate type, from non-spherical ones such as dust particles.

Tropospheric aerosols such as Kosa, sulfate aerosols and soot particles influence short-term climate variations, while stratospheric aerosols originating from volcanic gases and ash from large-scale volcanic eruptions can exert a significant influence on the climate over a period of several years. Understanding the distribution of aerosols and their sources, which are characterized by large spatial and temporal variations, is important for improved monitoring and projection of the global climate. Lidar systems are an effective tool in monitoring the behavior of aerosols.

Figure 3.1.19 shows vertical profiles of the aerosol scattering ratio averaged over three-month periods from December 2008 to November 2009. At heights of about 10 km or more, depending on the season, significantly lower amounts of aerosols are distributed in the stratosphere than in the troposphere, with amounts in the troposphere varying considerably by season. The large amounts of aerosols in the lower troposphere are attributable to their sources being located mainly on the earth’s surface. In the middle troposphere, aerosol amounts are larger in spring than in other seasons. This increment is mainly caused by Kosa transported from the Asian continent.

The elevated concentration of aerosols at heights from 8 to 20 km in the winter was probably influenced by the eruption of Kasatochi Volcano in the Aleutian Islands in August 2008. The peaks in aerosol concentration at heights from 15 to 20 km in the summer and autumn are probably attributable to the eruption of Sarychev Peak in the Kurile Islands in June 2009.
2 Monitoring of the ozone layer and ultraviolet radiation

Ozone is distributed mainly in the stratosphere at altitudes of 10 – 50 km, and absorbs harmful solar UV (ultraviolet) radiation, thus protecting the terrestrial ecosystem. Large-scale depletion of the ozone layer has been observed over Antarctica (mostly from September through November) since the early 1980s, creating what is known as the ozone hole. This is mainly caused by man-made chlorofluorocarbons (CFCs) and halons, and appears over Antarctica under unique meteorological conditions resulting from the topography of the Southern Hemisphere and the polar night. CFCs and halons have been used in a wide range of applications including cleaning solvents, aerosol propellants, refrigerants and fire extinguishers because of their high chemical stability and safety. This stability, however, means that CFCs hardly decompose in the troposphere and spread gradually into the stratosphere, where they release chlorine atoms that destroy ozone molecules. Ozone layer depletion, as characterized by the ozone hole, is observed in both hemispheres except in equatorial areas.

The mechanism of ozone layer depletion is described here. When CFCs reach an altitude of about 40 km in the stratosphere, they release chlorine atoms under solar UV radiation. As the released atomic chlorine moves around in the stratosphere, it reacts with the surrounding ozone to form molecular oxygen. After turning back to atomic chlorine, it then reacts with and destroys ozone again. This process creates a chain reaction that destroys ozone repeatedly.

2.1 Ozone layer

2.1.1 Global ozone layer

Deseasonalized, area-weighted monthly deviations of total ozone estimated from ground-based and satellite data are shown in Figure 3.2.1. Total ozone values decreased significantly in the 1980s and early 1990s, have shown little trend or a slight increase since the mid-1990s, and still remain lower than pre-1980 levels today. Ground-based observation indicates that the global mean total ozone for 2009 was 2.3±0.1% less than the value for 1979, which is used to represent pre-1980 levels.

The concentration of CFCs in the atmosphere has remained almost unchanged or has decreased gradually since the mid-1990s (see Section 1.1.4). This could be related to the fact that the decreasing tendency of total ozone has slowed since the mid-1990s. In the mid-latitudes of the Northern Hemisphere, however, there is an increasing tendency of total ozone in recent years, which some research indicates is largely attributable to a change in global-scale atmospheric circulation in the mid-latitudes of the Northern Hemisphere.

The global distribution of total ozone trends as derived from satellite observations is shown in Figure 3.2.2. The ozone trend figure indicates a decreasing tendency for the entire globe in 2009, and the decrease was more significant in mid and high latitudes than in low latitudes. In the mid-latitudes of the Northern Hemisphere, total ozone decreased 4 to 5% in 2009 compared to the value for 1979 as a long-term tendency.
Figure 3.2.1  Time-series representation of deviations of total ozone (in %) from the averages between 1970 and 1980. The closed circles indicate satellite data (70°N – 70°S), and the smooth solid line indicates the EESC (Equivalent Effective Stratospheric Chlorine) fitting line. The influences of known periodical natural variations (i.e. solar, volcanic and QBO) are subtracted. A total of 63 ground-based stations were used for the calculation, of which 54 were in the Northern Hemisphere and 9 in the Southern Hemisphere.

Figure 3.2.2  Global distribution of total ozone trends as derived from satellite observations. The trends were estimated from the EESC (Equivalent Effective Stratospheric Chlorine) curve fitting TOMS and OMI data, and expressed as a percentage of change (%) from 1979 to 2009 for the values on the curve. The TOMS and OMI satellite data were provided by NASA.
2.1.2  **Ozone layer over Japan**

JMA started observing the total amount of ozone at Tsukuba/Tateno in 1957, and has now extended this observation to the total amount and vertical distribution of ozone at several stations in Japan and at Syowa Station in Antarctica (see Figure 3.1.1).

Figure 3.2.3 shows a time-series representation of annual mean total ozone observed at Sapporo, Tsukuba/Tateno, Naha and Minamitorishima. The values mainly decreased in the 1980s and early 1990s. Since the mid-1990s, although there have been yearly variations, observations are characterized by a lack of trend (or a slightly increasing trend). The figure shows that total ozone values have generally decreased more clearly at higher latitudes. The annual mean total ozone values for 2009 at Sapporo and Tsukuba/Tateno were 2.9% and 0.7% less than the average from 1959 to 1980 respectively.

Monthly variations in total ozone over Japan for 2009 are shown in Figure 3.2.4. At all four stations, the monthly mean values were within one standard deviation of the averages seen over the period 1994 – 2008.

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**Figure 3.2.3**  Time-series representations of annual mean total ozone at Sapporo, Tsukuba/Tateno, Naha and Minamitorishima.
Figure 3.2.4  Monthly mean values of total ozone at four stations in Japan for 2009 (Sapporo, Tsukuba/Tateno, Naha and Minamitorishima). The closed circles indicate values for 2009, and the solid lines show the averages for 1994 – 2008, with bars indicating the ranges of standard deviation.
2.1.3 Ozone layer over Antarctica: the ozone hole

Satellite data show that the ozone hole in 2009 was at its largest on 17 September, with an area of 24 million km\(^2\) (see Figure 3.2.5 and the panel on the left of Figure 3.2.6). The annual maximum for the area was slightly smaller than its average value over the last ten years. One reason for the slightly smaller ozone hole in 2009 is that meteorological conditions over mid to high latitudes of the Southern Hemisphere from June to August were not favorable for severe ozone depletion over Antarctica. Another reason is that ozone-rich air was transported into the lower stratosphere over Antarctica for the period from the last half of September to early October when the ozone hole is usually at its largest for the year. Although the size of the hole changes in line with the weather conditions of the year as shown above, the ozone layer continues to be vulnerable because an abundance of ozone-depleting materials remains in the stratosphere.

Daily values of total ozone observed at Syowa Station in 2009 are shown in Figure 3.2.7. Total ozone levels were less than 220 m atm-cm from September to October. On 13 and 14 October, the annual minimum value of 135 m atm-cm was observed. Total ozone levels were more than 220 m atm-cm from November. The monthly mean total ozone values in November at the station were higher than normal, and approached pre-1980 levels (see Figure 3.2.8). This is attributed to the fact that the ozone-rich atmosphere outside the ozone hole covered Syowa Station because the hole’s center shifted from the South Pole to the Antarctic Peninsula as it shrank in November.

![Figure 3.2.5](image)

Figure 3.2.5 Distribution of total ozone in the Southern Hemisphere on 17 September 2009, when the area of the ozone hole reached its maximum for the year. The area of the ozone hole is defined as the region over which total ozone is equal to or less than 220 m atm-cm south of 45°S. This distribution was produced from OMI data provided by NASA.
Figure 3.2.6  Daily changes in the area of the ozone hole in 2009 (left) and changes in its annual maximum area since 1979 (right). In the figure on the left, the red dots show daily values for 2009, and the top and bottom of the dark purple area show daily maximum and minimum values respectively over the last ten years (1999 – 2008). In the figure on the right, the black horizontal line indicates the area of Antarctica. These figures were produced from TOMS data and OMI data provided by NASA.

Figure 3.2.7  Time-series representation of daily total ozone at Syowa Station in Antarctica from August to December 2009. The red dots show daily values for 2009, and the top and bottom of the dark purple area show the daily maximum and minimum values respectively since observation began in 1961. The dashed horizontal line indicates 220 m atm-cm.
Figure 3.2.8  Monthly mean values of total ozone at Syowa Station in Antarctica for 2009. The closed circles indicate the monthly values for 2009. The dotted line indicates monthly mean values before the appearance of the ozone hole (1961 – 1980), and the solid line shows values after its appearance (1994 – 2008), with bars indicating the range of standard deviation.

2.2 Solar UV radiation

Since ozone absorbs UV radiation, there is concern that a decrease in total ozone might increase the amount of harmful solar UV radiation that reaches the earth’s surface. JMA has been conducting UV observation at stations in Japan and at Syowa Station in Antarctica since 1990.

Figure 3.2.9 shows daily maximum UV Index (see the column at the end of this section) values for 2009 at three stations in Japan. Mainly because of solar elevation, these values are at their highest in summer, and are larger at lower latitudes. A UV Index rating of greater than three is observed throughout the year at Naha, and from March to October at Sapporo. Scattering of daily maximum UV Index values is caused mainly by weather conditions, which exert a significant influence on the amount of UV radiation reaching the earth’s surface.

Figure 3.2.9  Changes in daily maximum UV Index values at three stations in Japan for 2009. The solid lines show the means of the daily maximum UV Index levels (i.e. the averages over 1990 – 2008 for Tsukuba and 1991 – 2008 for the other stations).
Figure 3.2.10 shows monthly mean values for daily accumulation of erythemal UV radiation (see the column at the end of this section) for 2009 at the three stations. In this section, the term normal refers to the average over the period 1990 – 2008 for Tsukuba and that over the period 1991 – 2008 for Sapporo and Naha. The term almost normal is used to indicate values that are within the standard deviation from the monthly mean, and the term higher/lower than normal is used to indicate values higher/lower than almost normal. At Sapporo, the monthly means were higher than normal in January, April, May and September, and were lower than normal in February, March, June and July. In particular, the record-low monthly mean value for July was observed. At Tsukuba, the monthly mean values were almost normal for most of the year, and were higher than normal in April and October. In particular, the record-high monthly mean value for April was observed. At Naha, the monthly mean values were almost normal or higher than normal for most of the year. In particular, record-high monthly mean values were observed in January, February and May. Meanwhile, monthly mean values were lower than normal in October. These observations may have been significantly influenced by local weather conditions.

Monthly mean values of erythemal UV daily accumulation for 2009 at Syowa Station were almost normal in September, October and December, and were higher than normal in November due to the lower monthly mean total ozone (see Figure 3.2.11).

Somewhat increasing trends in erythemal UV radiation have been seen at Sapporo, Tsukuba and Naha since the early 1990s (see Figure 3.2.12). As total ozone was at its lowest around the early 1990s and there is a lack of trend (or a slightly increasing trend) in total ozone after the mid-1990s (as discussed in Section 2.1), the above increasing trends in erythemal UV radiation since the early 1990s cannot be attributed to the ozone change alone.

WMO reports that some unpolluted sites show decreasing UV radiation globally since the late 1990s. However, at other mid-latitude stations in the Northern Hemisphere, surface UV irradiance has continued to increase at a rate of a few percent per decade. This increase cannot be explained solely by ozone depletion, and may be attributable to a decreasing tendency in aerosol optical extinction and air pollution since the beginning of the 1990s as well as partially to decreasing cloudiness, as estimated from satellites. Similarly, the erythemal UV radiation trends over Japan may be attributable to changes in aerosol levels and weather conditions over the measuring sites, as no decreasing trends in total ozone are seen over the same period.
Figure 3.2.10  Monthly mean values of erythemal UV daily accumulation for 2009 at Sapporo, Tsukuba/Tateno and Naha in Japan. The closed circles indicate the values for 2009, and the solid lines represent the normal (i.e. the average over the period 1990 – 2008 for Tsukuba and 1991 – 2008 for the other stations), with the bars indicating the ranges of standard deviation.

Figure 3.2.11  Monthly mean values of erythemal UV daily accumulation for 2009 at Syowa Station in Antarctica. The closed circles indicate the values for 2009, and the solid line represents the normal (the average for 1993 – 2008), with the bars indicating the ranges of standard deviation.
Figure 3.2.12  Time-series representations showing the annual accumulation of erythemal UV from the beginning of observation up to 2009 at Sapporo, Tsukuba/Tateno and Naha in Japan. The straight lines indicate the regression for the whole observation period.

**Erythemal UV radiation and the UV Index**

Excessive exposure to solar UV is known to have adverse effects on human health, such as increased risk of skin cancer and cataracts. Erythemal UV radiation is widely used as a scale of UV radiation to grade its effect on the human body, calculated by considering different influences depending on wavelength. The UV Index is a standardized index for erythemal UV radiation, and in Japan the value normally ranges from 0 to 12. International organizations such as the World Health Organization (WHO) currently promote measures to protect the human body from UV using the UV Index (WHO et al., 2002). In Japan, the Ministry of the Environment suggests seeking shade when the index is higher than three, and advises against being outside when it is higher than eight during daytime hours.
3 Kosa (Aeolian dust) and acid rain

3.1 Kosa (Aeolian dust)

Kosa (Aeolian dust) is a meteorological phenomenon in which fine dust is blown up to an altitude of several thousand meters by cyclonic or other wind systems from deserts or cropland in semi-arid areas of the Asian continent, and is transported over long distances by westerly winds, resulting in haze or dustfall in downstream areas. The Taklimakan Desert, the Gobi Desert and the Loess Plateau are known as areas where dust particles are blown up. These particles are sometimes transported over more than a full circuit of the globe, crossing over the Pacific and Atlantic Oceans depending on weather conditions. Some research shows that the radius of the dust particles transported over Japan ranges from 1.6 to 1.8 μm, in contrast to sulfate aerosol particles, which are generally smaller than 1 μm in radius. While Kosa has long been observed mostly in spring and sometimes in autumn, recent research has revealed a persistent thin dust layer over Japan even in summer.

In the source areas of Kosa, large-scale dust storms may affect human health. In Japan, Kosa represents a traffic hazard and causes damage to laundry and vehicle bodies. Kosa affects not only social activities but also the global climate through processes such as absorption and scattering of solar radiation, absorption of infrared radiation and cloud formation. Floating dust weakly absorbs solar radiation and heats the atmosphere; at the same time, scattering reduces the amount of solar radiation arriving at ground level. According to the global dust transport model developed by the Meteorological Research Institute, the presence of dust results in a weak global cooling effect of −0.3 W/m² compared with a dust-free atmosphere. Moreover, chemical components of Kosa that fall into the ocean may largely influence its ecology by acting as a nutrient source for plankton in the ocean surface layer.

3.1.1 Kosa events over Japan in 2009

A total of 67 JMA meteorological stations (as of 31 December 2009) carry out observation of Kosa. The phenomenon is recorded whenever it is observed by station staff.

The number of days when any meteorological station in Japan observed Kosa (referred to below simply as the number of days) was 22 in 2009. The total number of stations observing Kosa as a total for the whole year (referred to below as the annual total number of stations) was 251 in 2009. The number of days and the annual total number of stations averaged over the period 1971 – 2000 are 20.3 and 163.0 respectively.

Figure 3.3.1 shows the daily numbers of stations observing Kosa in 2009. The phenomenon was observed in October and December for the first time in the last 17 and 16 years respectively.
3.1.2 Variations in Kosa

The largest number of days of Kosa observation since records began in 1967 was 47 in 2002 (Figure 3.3.2). The largest annual total number of stations was 789 in 2002 (Figure 3.3.3). The number of days and the annual total number of stations have often exceeded 30 and 300 respectively since 2000. Kosa has frequently been observed in recent years, but no clear long-term trend is identifiable due to large interannual variations.
Figure 3.3.3 The annual total number of stations observing Kosa in Japan (1967 – 2009), targeting the 67 stations that were active for the whole period.
3.2 Acid rain

Acid rain is a phenomenon in which acidic substances are deposited from the atmosphere to the ground, and plays an important role in forming the cycle of acidic substances together with the emission and transportation of atmospheric substances. In recent years, the deposition of acidic substances from the atmosphere to the ground has become a concern as it adversely influences the environments of rivers, soil and plants. The major acidic substances in the atmosphere are sulphuric acid and nitric acid, which are generated by photochemical reaction from the sulphur dioxide and nitrogen oxides emitted into the atmosphere from fossil fuel combustion.

There are two processes for acid deposition: wet deposition dissolved in rain, fog or snow, and dry deposition attached to aerosols or as gaseous substances. The influence of acid deposition depends on the total amount of acid deposited on the ground; a large amount of weakly acidic rain may cause more serious damage than a small amount of strongly acidic rain. Acid deposition influences the biosphere in two ways: indirect effects from changes in acidity, and direct effects from acid substances such as ammonia. In general, acidity in precipitation is expressed as a logarithm of hydrogen-ion concentration (pH = – log[H⁺]). Values smaller than 7 represent acidic conditions, while those larger than 7 are basic or alkaline. Hydrogen-ion concentration in precipitation is determined by equilibrium with other ion concentrations.

In June 2004, the Ministry of the Environment issued a comprehensive report on a survey into acid deposition conducted from 1983 to 2002. Below is a summary:

- The pH values averaged over the whole period at different observation sites ranged between 4.49 and 5.85, with an average of 4.77.
- The pH value remained almost stationary with small fluctuations before 1999, and decreased thereafter.
- This decrease is likely to be a result of sulphur dioxide emitted from the volcanic eruption on Miyakejima Island in the Izu Islands, but increased sulphur dioxide emissions from the Asian continent must also be considered.

3.2.1 Time-series representations of the annual mean pH of precipitation at JMA’s observation sites

Outlined below are the results up to 2008 that have so far been analyzed from samples.

The annual mean values of pH in precipitation for 2008 were 4.5 at Ryori and 5.2 at Minamitorishima. Figure 3.3.4 shows a time-series representation of annual mean acidity at Ryori and Minamitorishima. At Ryori, the value exceeded pH 5.0 in 1976 – 1977, and varied thereafter between pH 4.4 and 5.0. There is no significant trend at Ryori for the whole 33 years of observation. At Minamitorishima, the value ranged between pH 5.5 and 5.8 from 1996 to 2002, but has recently declined. The large decreases seen in 2003 and 2005 at Minamitorishima may be a result of active eruptions of Anatahan Volcano in the Northern
Mariana Islands, located 1,200 km southwest of Minamitorishima. The volcano erupted repeatedly from May to June 2003 and from April 2004 to September 2005. Meteorological analysis shows that volcanic gases frequently flowed over Minamitorishima during these times. However, the recent decrease in the acidity of precipitation reported at Chichijima Island in the Ogasawara Islands suggests the increased influence of acidic substances transported from the Asian continent.

![Figure 3.3.4 Time-series representations of annual mean values of pH at Ryori and Minamitorishima](image-url)
Map 1  Names of Japan’s island areas

Map 2  Names of Japanese regions used in this report
Map 3  Distribution of surface meteorological observation stations in Japan