Topics

I Unusual weather conditions on the Pacific side of northern and eastern Japan and extremely warm conditions in Okinawa/Amami in August 2017

During early to mid-August 2017, the Pacific side of northern and eastern Japan experienced unusual weather conditions. In August 2017, monthly mean temperatures were significantly above normal in Okinawa/Amami.

The Okhotsk High persisted during early-to-mid-August. Unusually, the North Pacific Subtropical High (NPSH) did not extend to mainland Japan and was shifted southward of its normal position in August.

I.1 Climate conditions (Figure I.1)

On the Pacific side of northern and eastern Japan, cloudy and rainy conditions were prominent in early-to-mid-August and monthly sunshine durations were significantly below normal in August. In particular, the 10-day sunshine duration ratio for mid-August on the Pacific side of northern Japan was 34%1 of the normal (the lowest since records began in 1961), and 10-day mean temperature anomalies for mid-August were below normal on the Pacific side of northern and eastern Japan. Due to persistent unusual weather conditions in early-to-mid-August, the date of Baiu withdrawal in Tohoku was unclear for the first time since 2009 (fifth time in southern part of the Tohoku region and sixth time in northern part of the Tohoku region since record began in 1951).

By contrast, monthly mean temperature anomalies for August in Okinawa/Amami were the highest since 1946 at +1.4°C above normal. Warmer-than-normal conditions also persisted in the region from August to October, and monthly mean temperature anomalies for September were tied with 2014 as the highest on record since 1946 (+1.3°C above normal).

1 https://www.data.jma.go.jp/gmd/cpd/cgi-bin/view/kikohyo/en.php
I.2 Characteristics of atmospheric circulation

(1) Characteristics related to the unusual weather conditions on the Pacific side of northern and eastern Japan

During summer 2017, equatorial intraseasonal oscillation was clearly observed. Convective activity was suppressed around the Maritime Continent in late July, and afterward convection was inactive over and around the Philippines during early-to-mid-August (Figure I.2-1 (a)). In association with inactive convection over and around the Philippines, the North Pacific Subtropical High (NPSH) unusually did not extend to mainland Japan and was shifted southward of its normal position (Figure I.2-1 (b)). There is a known correlation between convection in the vicinity of the Philippines and the intensity of the NPSH around Japan, and these relationships are called the PJ (Pacific – Japan) pattern (Nitta, 1987; Kosaka and Nakamura, 2010).

During early-to-mid-August, the westerly jet stream over Eurasia meandered and a blocking high developed around Eastern Siberia (Figure I.2-1 (c)). In association with the development and persistence of the blocking high, the Okhotsk High persisted in the lower troposphere (Figure I.2-1 (b)) and brought cool, wet northeasterly flows to the Pacific side of northern and eastern Japan. Typhoon Noru (T05) also passed over and around Japan in early
August, and low-pressure systems and fronts subsequently passed repeatedly over its mainland. Atmospheric conditions over eastern Japan were often unstable in association with upper-level cold-air masses.

During early-to-mid-August, these atmospheric circulation phenomena caused an increase in the number of cloudy and rainy days on the Pacific side of northern and eastern Japan, with sunshine durations in particular being significantly below normal.

(2) Characteristics related to warmer-than-normal conditions in Okinawa/Amami
As mentioned in (1), convective activity was suppressed over and around the Philippines from early to mid-August and the NPSH was enhanced over the seas south of Japan. As a result, the NPSH frequently covered Okinawa/Amami, and adiabatic heating associated with downward flow and westerly warm air advection in the lower troposphere brought significantly warmer conditions than normal. The Tibetan High (which extended southward to cover Okinawa/Amami) in the upper troposphere and enhanced solar radiation may also have contributed to the significantly above-normal temperatures in Okinawa/Amami.

The NPSH was persistently enhanced to the seas south of Japan and was present from August to October, presumably due to active convection over the Maritime Continent and positive SST (sea surface temperature) anomalies in the western tropical Pacific in addition to equatorial intraseasonal oscillation.

Primary factors contributing to the unseasonable weather conditions on the Pacific side of northern and eastern Japan and the warmer-than-normal conditions in Okinawa/Amami during early-to-mid-August 2017 are summarized in Figure I.2-2.

Figure I.2-1 (a) Outgoing longwave radiation (OLR) anomaly, (b) sea level pressure (contours) and anomaly (shade), (c) 500-hPa height (contours) and anomaly (shade) for the period from 11 to 20 August 2017
The contours are drawn at intervals of (b) 4 hPa and (c) 60 m. The base period for the normal is 1981 – 2010.
Figure I.2-2 Primary factors contributing to the unseasonable weather conditions observed during the early to mid-August 2017

Solid line show elements for 2017, and dashed lines show the normal.
II Appearance of the first Kuroshio large meander for 12 years

A large meander in the Kuroshio current has been observed since late August 2017.

II.1 The Kuroshio current
The strong Kuroshio ocean current flows along Japan’s southern coast at a rate sometimes exceeding 2.5 m/s (round 5 knots).

A small meander that developed southeast of Japan’s Kyusyu Island in late March 2017 and propagated eastward to waters off the country’s Tokai region in late August is considered to have induced this Kuroshio large meander, which is the first since August 2005 and has continued (Figure II.1).

Fig II.1 Analysis of oceanic currents at a depth of 50 m on 1st November 2017
The figure shows the results of analysis using ocean model output and observation data. Red represents rapid flow. The black line represents the typical non-large-meander Kuroshio path. The star shows the location of Akabane referred to in Figure II.3.

Since September 2017, JMA has conducted oceanic observation from its own research vessels and conducted several examinations of temperature distribution corresponding to the Kuroshio’s path (Figure II.2).
Fig. II.2  Observation results from JMA’s Ryofu Maru research vessel, 22nd December 2017
Top: ocean currents (solid red line: shipping route; dashed red arrow: estimated Kuroshio path; black lollipops: observed ocean current speed and direction)
Bottom: depth-wise distribution of sea temperature from A to C
B represents the positions at which the strongest ocean current was observed along the route.
II.2 Influence of the Kuroshio large meander

Any change in the Kuroshio path can influence economical shipping routes and fishing grounds, and can cause rough seas associated with strong current movement.

Once the Kuroshio large meander appears, coastal sea levels from the Tokai region to the Kanto region tend to rise. If sea level rises associated with typhoons or low-pressure systems occur simultaneously, damage caused by inundation in low-lying land areas is expected to be exacerbated by the influence of the meander.

The intense Typhoon Lan of 2017 made landfall on Shizuoka Prefecture before heading northeast. Sea levels in the prefectures of Aichi, Shizuoka and Mie in the Tokai and high waves region were 20 – 30 cm higher than normal due to the meander at that time. Local storm surges were exacerbated by its presence in addition to the influences of the typhoon itself and spring tide/high tide conditions (Figure I.3, Table I.1).

![Fig. II.3  Sea level deviations at Akabane (Aichi prefecture) from 15 to 26 October 2017](image)

**Table II.1** Maximum sea level deviations from 22 – 23 October 2017

<table>
<thead>
<tr>
<th>Observation station</th>
<th>Momentary value</th>
<th>Smoothed value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akabane (Aichi Prefecture)</td>
<td>+162 cm</td>
<td>+117 cm</td>
</tr>
<tr>
<td>Maisaka (Shizuoka Prefecture)</td>
<td>+146 cm</td>
<td>+123 cm</td>
</tr>
<tr>
<td>Toba (Mie Prefecture)</td>
<td>+121 cm</td>
<td>+107 cm</td>
</tr>
</tbody>
</table>

II.3 Information on the Kuroshio current

JMA provides ocean current analysis and monthly forecasts every 10 days based on observational data and ocean model results. The Agency runs a portal site to provide information on the Kushiro large meander, including synopses of the latest situation, one-month forecasts and the results of observations conducted by JMA research vessels.

The path of the meander is stable, and precedents indicate a tendency for persistence over periods of a year or more (Table II.2). JMA continues to monitor the situation and provide related information.
Table II.2  Kuroshio large meander precedents

<table>
<thead>
<tr>
<th>Period</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) August 1975 – March 1980</td>
<td>4 years, 8 months</td>
</tr>
<tr>
<td>(2) November 1981 – May 1984</td>
<td>2 years, 7 months</td>
</tr>
<tr>
<td>(3) December 1986 – July 1988</td>
<td>1 year, 8 months</td>
</tr>
<tr>
<td>(4) December 1989 – December 1990</td>
<td>1 year, 1 month</td>
</tr>
<tr>
<td>(5) July 2004 – August 2005</td>
<td>1 year, 2 months</td>
</tr>
<tr>
<td>(6) August 2017 –</td>
<td></td>
</tr>
</tbody>
</table>
The smallest Antarctic ozone hole in 29 years

- The maximum area of the Antarctic ozone hole in 2017 was 18.78 million square kilometers, which was the smallest since 1988. This is partially attributed to the mitigation of ozone layer destruction by much higher stratospheric temperatures.
- A return to Antarctic ozone values similar to those of the 1980s is likely in the second half of this century. Accordingly, it is important to continue monitoring stratospheric ozone in the region.

Data from satellite observations conducted by the National Aeronautics and Space Administration (NASA) show that the ozone hole developed in August 2017 as in previous years. Its disappearance was recorded on 19 November, which was earlier than usual. After August the hole was smaller than the mean for the last decade, and in the second half of September it was smaller than the smallest value recorded in the last decade (Figure III.1, left). The maximum area for 2017 was recorded on 10 September at 18.78 million km², which was the smallest since 1988 and just 1.4 times the area of Antarctica itself (Figure III.1, right).

![Figure III.1 Time-series representations of the area of the ozone hole over Antarctica](image)

Left: 2016 and 2017
Right: maximum area
Source: JMA (based on NASA TOMS/OMI and NOAA-TOVS satellite observation data)

The formation and development of the ozone hole are closely related to atmospheric concentrations of ozone-depleting substances (ODSs) such as chlorofluorocarbons (CFCs), and to weather conditions over Antarctica. Concentrations of ODSs have gradually decreased since the second half of the 1990s thanks to the regulation of their production under the 1987 Montreal Protocol, but still remain relatively high (Figure 3.2-7). Due to the skewed distribution of a cold vortex over Antarctica from winter to spring 2017, temperatures region-wide were higher than the mean for the last decade (Figure III.2). This situation mitigates ozone layer destruction and ozone hole development via the mechanism described at the end of this section.

![Figure III.2 Time-series representations of area-averaged (60 – 90° south) 50-hPa temperatures over Antarctica](image)

Red line: 2017
Black line: 2007 – 2016 mean
Grey area: 2007 – 2016 standard deviation
Purple area: 2007 – 2016 temperature range
Based on JRA-55 data
The results of scientific assessments on ozone depletion, including commentary on current conditions and future expectations, are periodically issued by the World Meteorological Organization (WMO) and the United Nations Environmental Programme (UNEP). The latest such assessment in 2014 predicted that a reduction in concentrations of ODSs would bring the global ozone concentration back to levels last seen in the 1980s by the end of the first half of this century thanks to the effective measures stipulated under the Montreal Protocol, but this is unlikely to happen in the Antarctic region until the second half of the century or beyond.

It is expected to take several decades for the ozone layer to return to the situation seen in the 1980s due to the time and effort involved in eliminating anthropogenic effects such as those caused by ODSs from the atmosphere. The year 2017 marks the 30th anniversary of the Montreal Protocol, which has been enhanced for comprehensive control regarding the production of ODSs such as certain CFCs and hydrochlorofluorocarbons (HCFCs) worldwide, and has produced significant environmental benefits.

Concentrations of CFCs may have decreased in recent years, but those of HCFCs and hydrofluorocarbons (HFCs), which are used widely as substitutes for CFCs and HCFCs, are increasing. HFCs affect the ozone layer only indirectly, but are still categorized as greenhouse gases. Accordingly, a need to control and gradually reduce their concentrations was identified in the Kigali Amendment to the Montreal Protocol at the 28th Meeting of the Parties on 15 October 2016 in Kigali, Rwanda, and the agreement will become effective in January 2019. JMA will continue its focused monitoring of the ozone layer to support these worldwide efforts for more effective ozone protection.

**The mechanism of polar ozone destruction**

When CFCs and/or HCFCs are dissolved by ultraviolet rays in the upper stratosphere (at altitudes of around 40 km), the resulting chlorine atoms catalyze a chain reaction that causes ozone layer destruction. Chlorine atoms are subsequently transported into the lower stratosphere and generally converted to a relatively inert species (ClONO₂ or HCl). Polar vortices forming in the stratosphere during winter significantly restrict atmospheric circulation, causing isolation from adjacent regions. In the absence of sunlight, the temperature in the interior of the polar vortex is extremely low due to radiative cooling. At stratospheric temperatures below −78°C, condensed nitric acid and water vapor cause polar stratospheric clouds (PSCs) to form. At the surface of PSCs, chlorine molecules generated from chloride compounds via a particular chemical reaction accumulate in winter. When spring comes, chlorine atoms generated from chlorine molecules via photodissociation act as catalysts in the destruction of ozone. This mechanism promotes the rapid deterioration of ozone and the formation of the ozone hole over Antarctica.

![Figure III.3 Time-series representations of areas with temperatures below -78°C (at 50 hPa) over Antarctica (the temperature of -78°C is associated with PSC formation)](image-url)

- Red line: 2017
- Black line: 2007 – 2016 mean
- Grey area: 2007 – 2016 standard deviation
- Purple area: 2007 – 2016 temperature range
- Based on JRA-55 data
IV Ocean acidification in the global ocean

- Surface seawater pH values have shown a clear long-term trend of decrease in vast areas of the global ocean. The rate of decrease is approximately 0.018 pH per decade (1990–2016).

A long-term trend of pH decrease known as ocean acidification is observed due largely to the dissolution of atmospheric carbon dioxide (CO₂) in ocean water. As the concentration of atmospheric CO₂ is steadily increasing, there are concerns that oceans may become even more acidic in the future and affect the marine ecosystems of lifeforms such as plankton and coral.

JMA has monitored monthly sea surface pH values since 1990 based on a global oceanographic observation database containing information from JMA’s Ryofu Maru and Keifu Maru research vessels. In November 2017, the Agency started providing ocean acidification monitoring information in the world’s first periodically updated data service of its kind.

The results of analysis show a decrease in surface seawater pH of approximately 0.018 pH per decade (1990 – 2016) (Figures IV.1 and IV.2). According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2013), average global surface seawater pH is thought to have decreased by 0.1 due to oceanic uptake of atmospheric CO₂ emitted as a result of human activity since pre-industrial times (1750) (representing a decrease of approximately 0.004 pH per decade). These data suggest a recent rate of ocean acidification higher than any time in the past 250 years.

Due to the fundamental importance of such information in validating climate models and considering adaptation plans, JMA remains committed to observation via research vessels and the provision of related data online.

Figure IV.1  Rate of pH change in oceans globally
The solid line is a time-series representation of the pH anomaly from the normal (average from 1990 to 2010) in oceans globally. The shaded area and dotted line represent the standard deviation range (±1σ) and the long-term trend, respectively. The ‘±’ symbol indicates a 95% confidence interval.

Figure IV.2  pH distribution in 1990 (left) and 2016 (right) in oceans globally