Factors behind record-high temperatures over Japan in summer 2025 and dry conditions in July, and the large-scale atmospheric circulation behind heavy rainfall in the first half of August

30 September 2025
Tokyo Climate Center (TCC), Japan Meteorological Agency (JMA)
https://www.data.jma.go.jp/tcc/tcc

Summary

Characteristics of record-high temperatures in June – August (summer) 2025 and dry conditions in July in Japan:

- Summer mean temperatures far exceeding previous records set in 2023 and 2024
- A new national record-high daily maximum temperature and unprecedented cumulative numbers of weather stations observing daily maximum temperatures exceeding certain thresholds
- Early seasonal march with the earliest-ever withdrawal of the Baiu rainy season over many regions, and consequent record-dry conditions over Hokuriku region (Fig. A) in July

Factors behind these characteristics:

- Enhanced convection over the Asian monsoon region from the early summer monsoon period in association with above-normal ocean temperatures in the tropical western Pacific
  - ➢ This contributed to a markedly poleward-shifted subtropical jet over Eurasia from June onward and the Tibetan High extension toward Japan.
  - ➢ The North Pacific Subtropical High (NPSH) extended toward Japan in association with unprecedented intensification of cumulus convection to the east of the Philippines.
  - ➢ Both the Tibetan High and the NPSH covered areas around Japan, causing temperature rise under a dominant anomalous descent.
- A long-term tropospheric warming trend associated with global warming and pronounced above-normal tropospheric temperatures over the mid-latitude Northern Hemisphere in association with persistent remarkably high sea surface temperatures (SSTs) in the area in recent years

The Japanese Reanalysis for Three Quarters of a Century (JRA-3Q; Kosaka et al. 2024)[1] and Merged Satellite and In-situ Data Global Daily Sea Surface Temperature (MGDSST; Kurihara et al. 2006) datasets were used in this analysis for atmospheric circulation and SSTs, and NOAA Climate Prediction Center (CPC) Blended Outgoing Longwave Radiation (OLR) data were used for inference of tropical convective activity.

In-situ station data on surface air temperature over Japan were obtained from the JMA Automated Meteorological Data Acquisition System (AMeDAS).

The base period for the normal is 1991 to 2020. The term "anomaly" as used in this report refers to deviation from the normal.

[1] https://jra.kishou.go.jp/JRA-3Q/index_en.html

Introduction

In summer 2025, Japan experienced sweltering heat with above-normal surface air temperatures in northern, eastern and western Japan, and significantly high temperatures from mid-June to early August. In July, record-dry conditions were observed over parts of the country due to an inactive Baiu front and a suppressed supply of moisture. The nation's Hokuriku and Kyushu regions experienced heavy rainfall in the first half of August.

This report outlines discussions held by the JMA Advisory Panel on Extreme Climatic Events (comprised of prominent climate science academics and researchers) on 5 September 2025 to summarize primary factors behind these anomalous climate conditions (Fig. 0). The details provided are as of the time of the meeting.

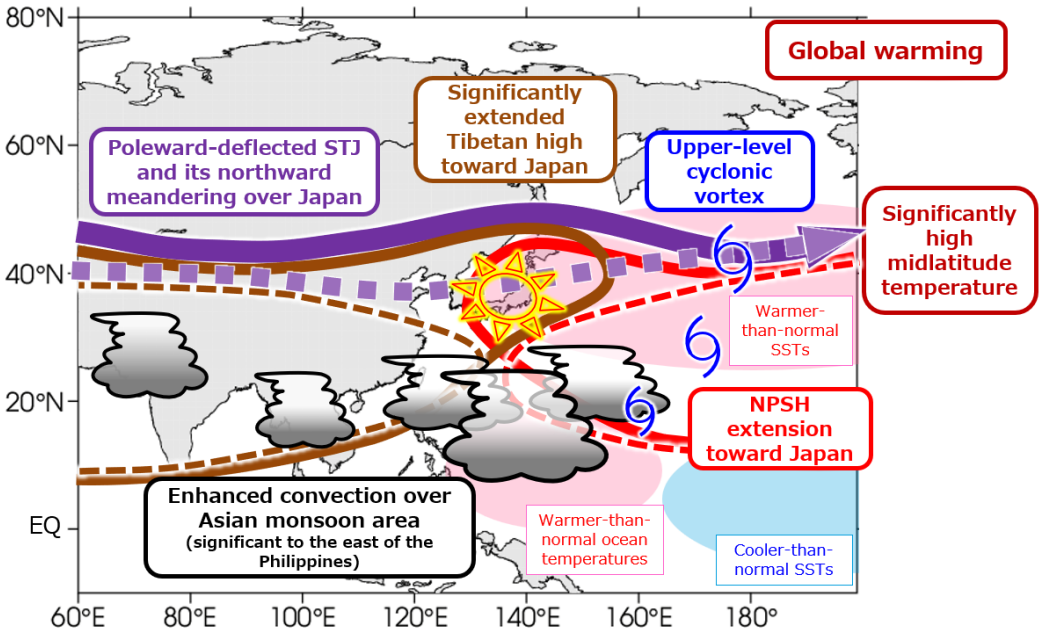

Figure 0 Large-scale factors behind record-high temperatures and dry conditions in summer 2025

"STJ," "SST" and "NPSH" stand for subtropical jet, sea surface temperature and North Pacific Subtropical High, respectively. Dashed lines show normal positions.

1. Climate conditions in summer 2025

1-1. Record-high temperatures

- Surface air temperature anomalies over Japan in summer 2025 were significantly positive nationwide except in Okinawa/Amami, with values in northern, eastern and western Japan at their highest since 1946. The record-high summer mean temperature anomaly over the country in 2025 was +2.36°C, far exceeding the previous 2023 and 2024 records (both +1.76°C) (Fig. 1-1).
- On 5 August, a new national daily maximum temperature of 41.8°C was recorded at Isesaki in Gunma Prefecture, north of Tokyo, accompanied by unprecedented cumulative numbers of weather stations observing daily maximum temperatures exceeding 35 and 40°C (Fig. 1-2).

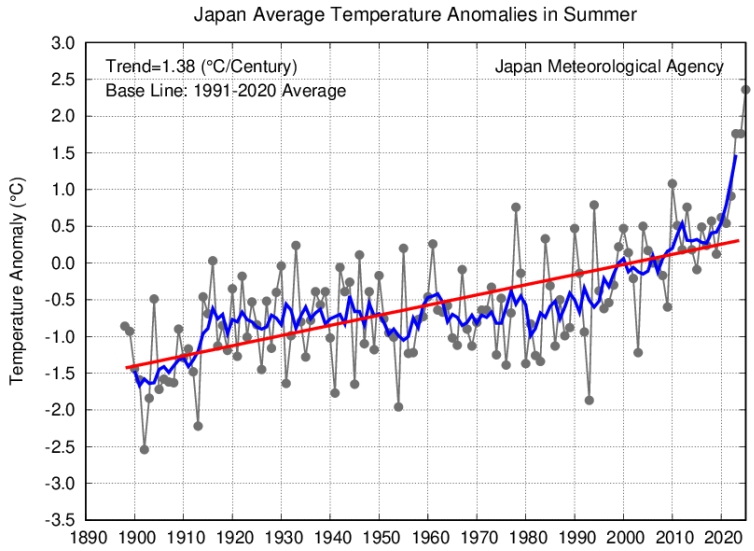

Figure 1-1 Interannual time-series representation of surface air temperature anomalies (unit: °C) in summer averaged over Japan from 1898 to 2025
Blue and red lines denote the five-year running mean and the linear trend, respectively.

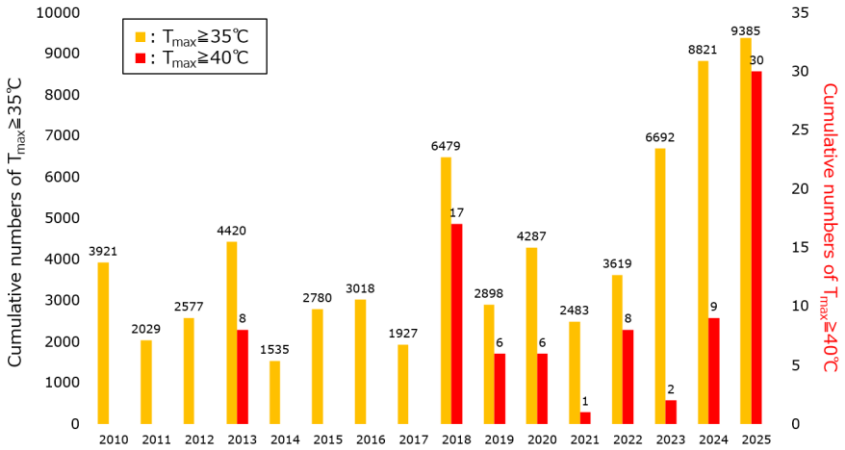

Figure 1-2 Interannual time-series representation of cumulative numbers of AMeDAS stations recording daily maximum temperatures (T_{max}) of 35°C or higher (orange; left axis) and 40°C or higher (red; right axis) from 2010 to 2025

1-2. Dry conditions in July

- In July, record-dry conditions were observed over parts of Japan (Fig. 1-3) due to an inactive Baiu front and a suppressed supply of moisture.
  - ➢ Most regions experienced early onset and withdrawal of the Baiu rainy season in association with an early seasonal march. Many regions outside the Tohoku area experienced their earliest-ever withdrawal of the Baiu rainy season in June.
  - ➢ Monthly precipitation amounts were significantly below normal on the Sea of Japan side. Those in Hokuriku region were the lowest for July since 1946.
  - ➢ Parts of the country experienced significantly above-normal monthly sunshine durations, with some recording the longest for July since 1946.

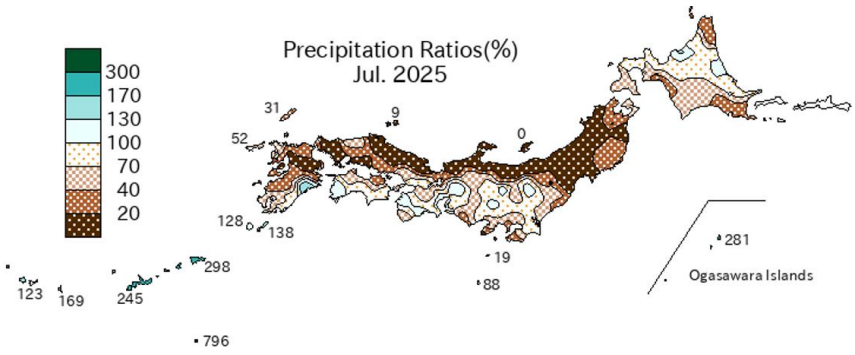

Figure 1-3 Monthly precipitation ratios against the normal (unit: %) in July 2025

1-3. Heavy rainfall in the first half of August

- Hokuriku and Kyushu regions experienced record-heavy rainfall in the first half of August (Fig. 1-4) due to intensified stationary front activity.

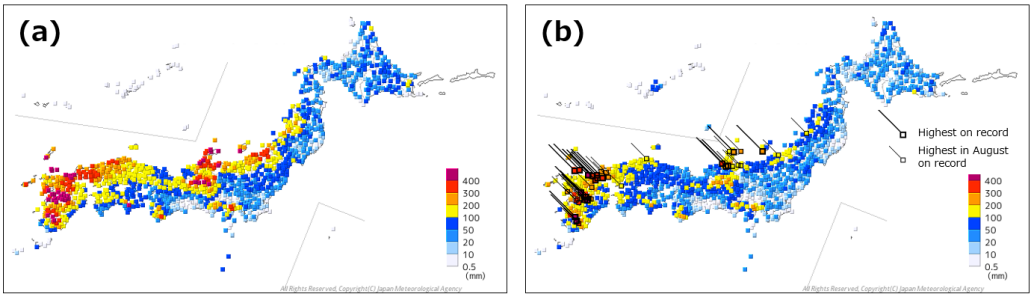

Figure 1-4 Precipitation (unit: mm) from 6 to 12 August 2025
(a) Seven-day total and (b) maximum 24-hour precipitation. Thick and thin squares with short lines indicate stations at which 24-hour maxima were the highest for all seasons and for August, respectively.

1-4. Global extreme climate events

- Remarkably high temperatures were observed over wide areas of mid-latitude Eurasia (Fig. 1-5).
- Monthly anomalies of global average surface temperature (i.e., the combined average of near-surface air temperature over land and SSTs) in June and July were +0.37°C and +0.42°C, both of which were the third highest since 1891.

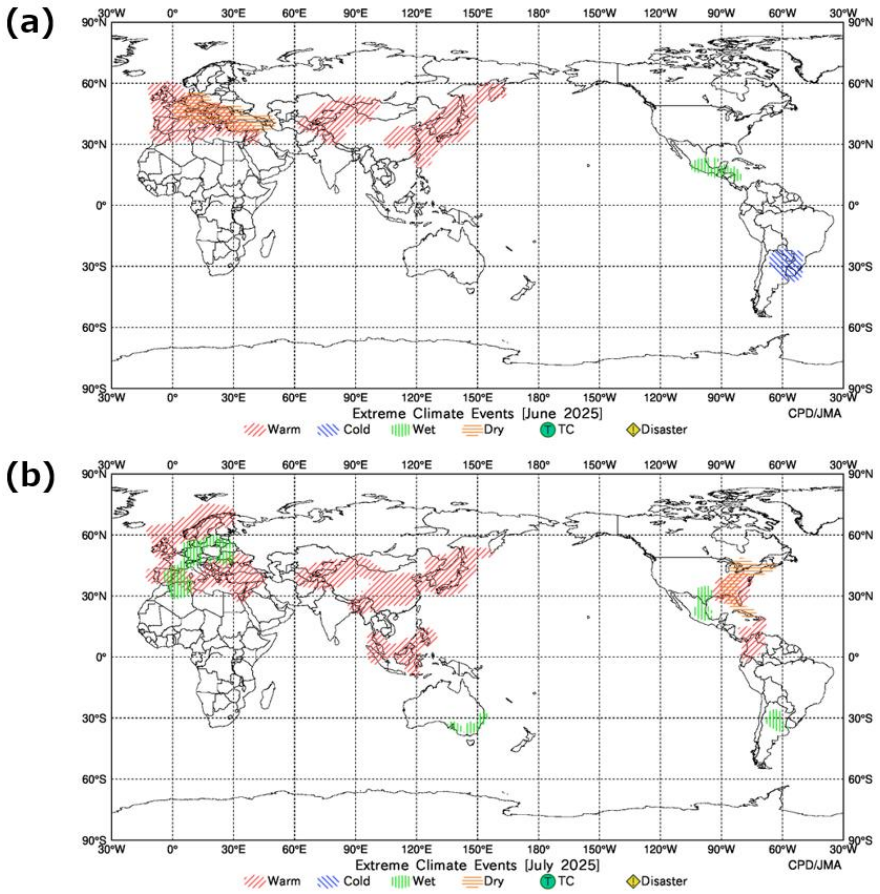

Figure 1-5 Global extreme climate events in (a) June and (b) July 2025
Red, blue, green and yellow hatched areas show extreme warm, cold, wet and dry climate events, respectively, defined as phenomena occurring once every 30 years or less. The figure is based on CLIMAT report data. Areas with missing or unreceived data are not shown.

2. Large-scale atmospheric circulation and related influence on climate conditions over Japan

- The subtropical jet (STJ) around Japan significantly shifted poleward around Sakhalin from mid-June to July, with the shift persisting in August (Fig. 2-1). This caused Baiu front inactivity around Japan at the end of June, corresponding to the record-early withdrawal of the Baiu rainy season in eastern and western Japan. The Tibetan High south of the STJ markedly extended northeastward, causing higher tropospheric temperatures around the country.
- On an intraseasonal timescale, the STJ around Japan markedly meandered northward in association with Rossby wave propagation across Eurasia in a Silk Road pattern (SRP, Enomoto et al. 2003; Enomoto 2004; Kosaka et al. 2009) around mid-June, early July, and late July. The intraseasonal SRP intensification contributed to further extension of the Tibetan High toward Japan (Fig. 2-2).
- Patches of upper-level cyclonic vortices with high-potential vorticity anomalies detaching from the intensified mid-Pacific trough moved westward toward the south of Japan, contributing to enhanced convection to the east of the Philippines (Section 3).
- The low-level North Pacific Subtropical High (NPSH) extended toward areas from mainland to northern Japan (Fig. 2-1). Both associated anomalous descent and increased downward solar radiation under the NPSH contributed to high surface air temperatures over the country. On a local scale, intensified downslope winds associated with the Foehn effect also caused higher local surface air temperatures.
- In the first half of August, the STJ meandered southward in association with the phase-shifted SRP (Fig. 2-2). A stationary front from China to mainland Japan was active under moist airflow originating from the Asian monsoon area. Record-heavy rainfall in Hokuriku and Kyushu regions of Japan was associated with intensified moist airflow along the periphery of the southwestward-extended NPSH toward the stationary front (Fig. 2-3).

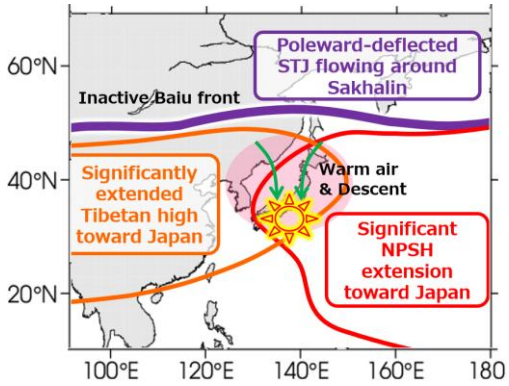

Figure 2-1 Large-scale atmospheric circulation and related influence on climate conditions over Japan in July 2025

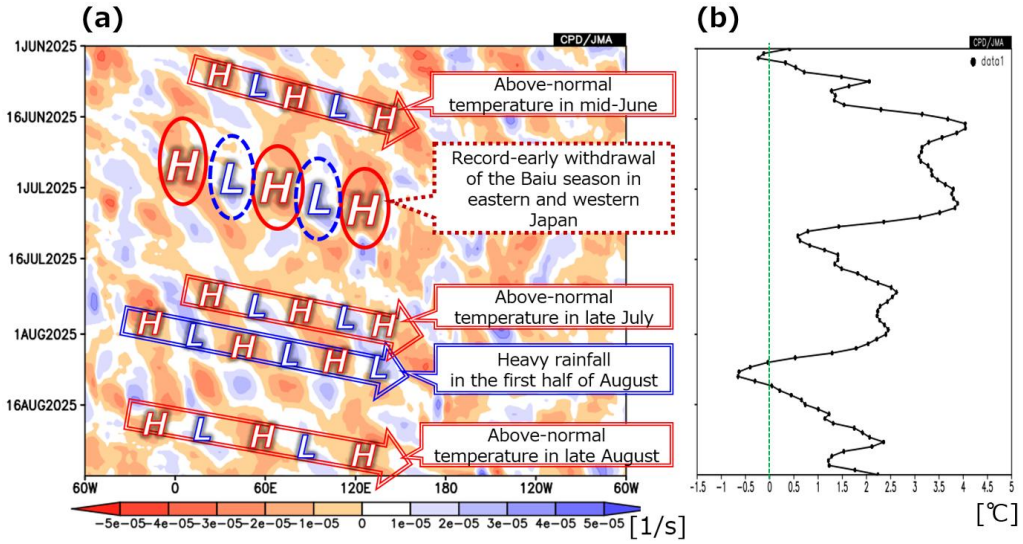

Figure 2-2 (a) Longitude-time cross section of 5-day running mean 200 hPa vorticity anomalies (unit: s^{-1}) averaged over 30 – 60°N and (b) 5-day running mean 850 hPa temperature anomalies (unit: °C) around Japan [31.5 – 45°N, 130 – 145°E] from June to August 2025

"H" and "L" in (a) represent anticyclonic and cyclonic circulation anomalies, respectively. Arrows denote eastward propagation of Rossby waves, and ellipses represent quasi-stationary waves.

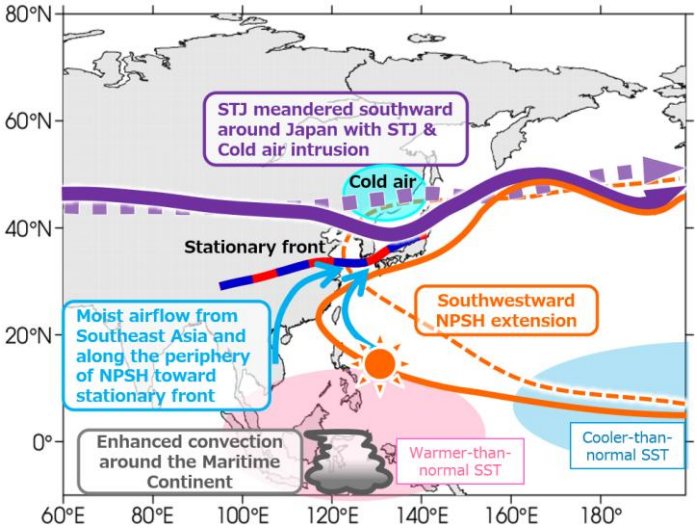

Figure 2-3 Atmospheric circulation related to record-heavy rainfall from 6 to 12 August 2025

Dashed lines show normal positions.

3. Tropical convection and related influence on large-scale atmospheric circulation

- The summer Asian monsoon onset was several weeks earlier than normal with persistent enhancement until mid-July, contributing to the intensified Tibetan High and a persistently poleward-shifted STJ from Eurasia to Japan (Figs. 2-1 and 3-1).
- In July, record convection enhancement to the northeast of the Philippines (Fig. 3-2) triggered a Pacific-Japan (PJ) pattern (Fig. 3-3; Nitta 1987; Kosaka and Nakamura 2006, 2010).
- Convective activity exhibited notable sub-monthly variations in association with boreal-summer intraseasonal oscillation (BSISO; Lee et al. 2013; Kikuchi 2021). From the end of July to early August, BSISO-related northward-moving enhanced convection was clearly seen from the tropics to the subtropics. To the south of this enhancement, anticyclonic circulation anomalies shifted northward from the Philippines to the south of Japan, corresponding to the southwestward extension of the NPSH. Warm moist airflow along the periphery of the extended NPSH in addition to that originating from the Asian monsoon area moving toward Japan in early August caused heavy rainfall in Hokuriku and Kyushu regions of the country.

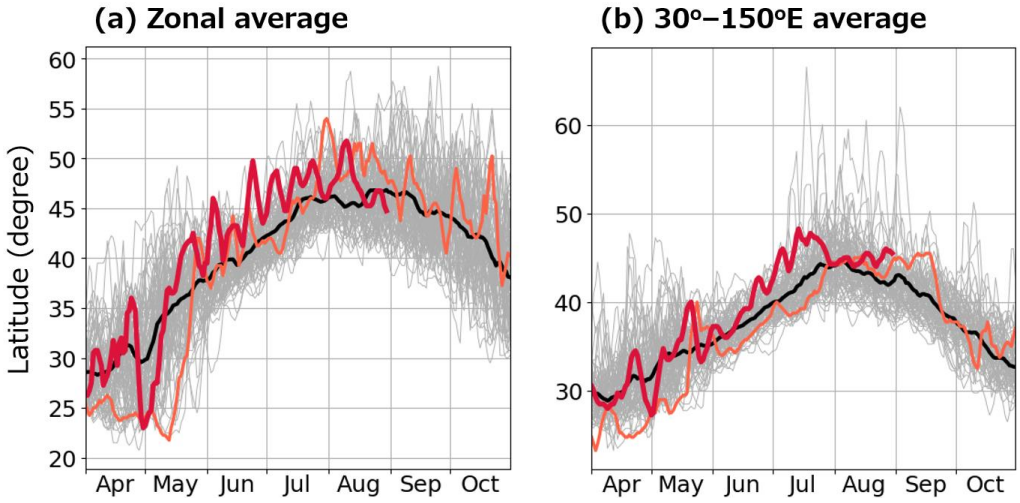

Figure 3-1 Time-series representation of STJ axis latitudinal positions derived from zonal wind at 200 hPa from April to October

(a) Zonal average and (b) 30 – 150°E average. Red, orange, black and grey lines denote 2025, 2024, the normal and other individual years from 1948 to 2023, respectively.

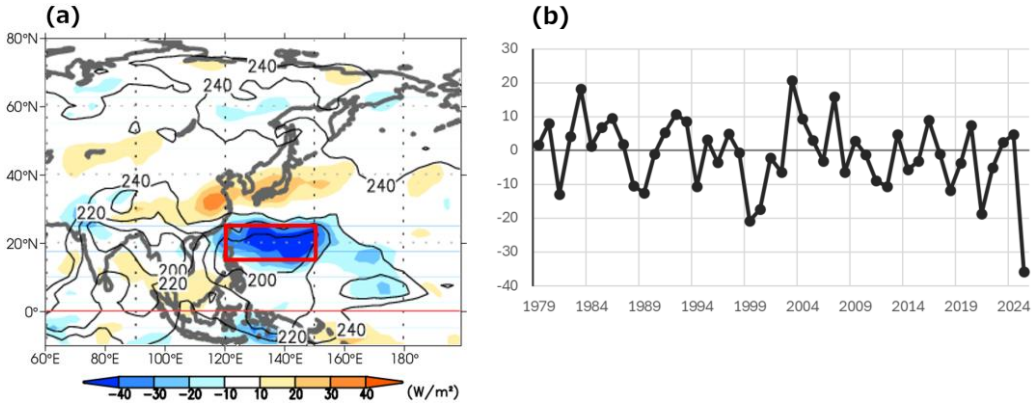

Figure 3-2 (a) OLR (contours; unit: W/m^2) and corresponding anomalies (shading) averaged for July 2025 and (b) interannual time-series representation of OLR anomalies to the northeast of the Philippines [15 – 25°N, 120 – 150°E] (red box in (a)) in July from 1979 to 2025

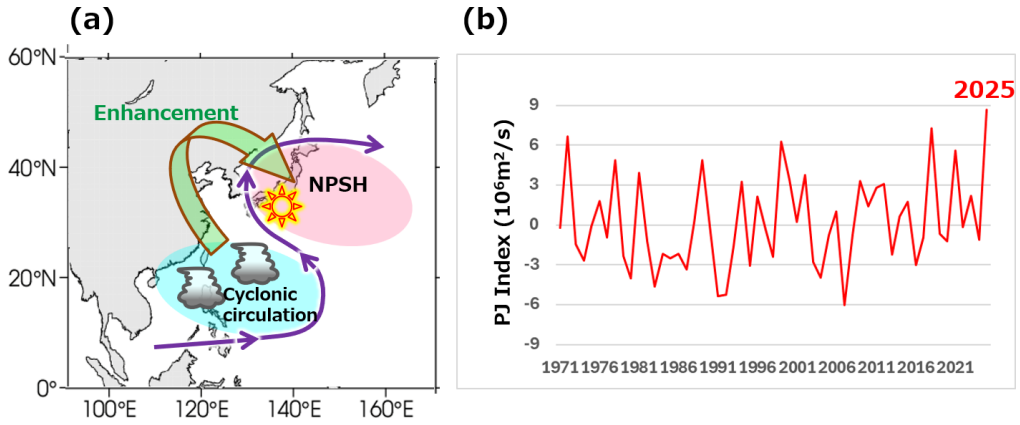

Figure 3-3 (a) Schematics for PJ pattern and (b) interannual time-series representation of PJ pattern indices in July from 1971 to 2025

Values in (b) are defined as the difference between 850-hPa stream function anomalies (unit: 10^6 m^2/s) averaged over [32.5 – 42.5°N, 145 – 165°E] and [16.25 – 26.25°N, 115 – 135°E].

4. Oceanographic conditions and related influence on large-scale atmospheric circulation

- Summer mean SSTs in the tropical Pacific were above normal in western parts and below normal from central to eastern parts in a pattern exhibiting La Niña-like characteristics (Figs. 4-1 and 4-2), although JMA's conditions for the definition of a La Niña occurrence were not satisfied. This zonal contrast of SST anomalies possibly contributed to enhanced convection over the summer Asian monsoon area.
- In the tropical western Pacific, particularly to the east of the Philippines, ocean temperatures to a depth of several hundred meters were significantly above normal, possibly contributing to the record enhancement of convection observed to the northeast of the Philippines (Fig. 3-2).
- SSTs in the mid-latitude North Pacific were significantly above normal (Fig. 4-2), in addition to the aforementioned tropical SST anomalies, possibly contributing to the remarkably above-normal mid-

latitude tropospheric temperatures associated with the feedback effect of the air-sea interaction behind poleward-shifted STJ persistence (Fig. 4-1).

- Positive SST anomalies to the east of Japan were further intensified from the second half of June to the first half of July in association with the northward-meandering STJ around Japan. The significantly above-normal surface air temperatures observed around northern Japan were possibly attributable to the high SSTs observed around the country through an enhanced greenhouse effect due to increased moisture. Additionally, increased downward solar radiation owing to reduced low-level cloudiness related to the high SSTs (Norris and Leovy 1994) may be linked to the persistently above-normal SSTs and surface air temperatures observed around northern Japan.
- The negative phase of the Pacific Decadal Oscillation (PDO; Mantua et al. 1997; Nakamura and Yamagata 1999; Newman et al. 2016), which has persisted since around 2020, is a possible factor behind these anomalous SSTs (Fig. 4-1).

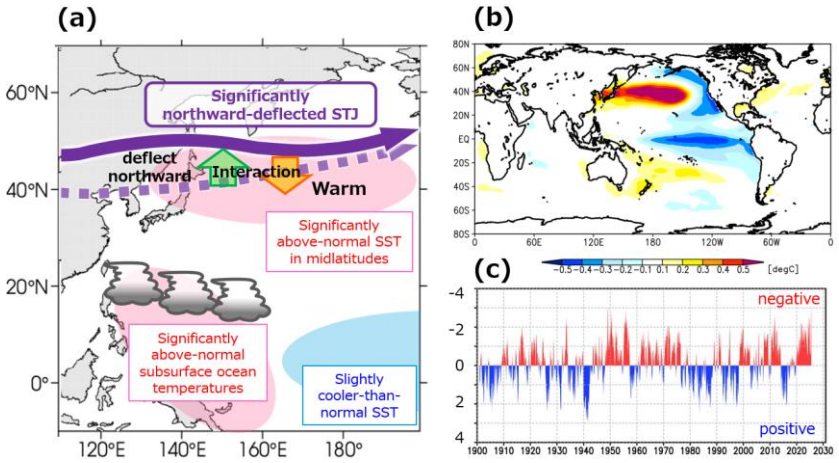

Figure 4-1 (a) Oceanographic conditions and related influence on large-scale atmospheric circulation, (b) global pattern of SST anomalies (unit: °C) associated with the negative phase of the PDO, and (c) time-series representation of PDO indices

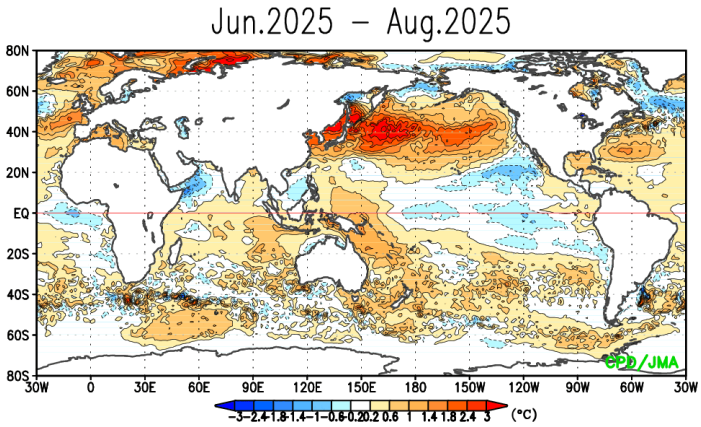

Figure 4-2 Global SST anomalies averaged over summer 2025

5. Influence of global warming

- A joint research team from the Ministry of Education, Culture, Sports, Science and Technology (MEXT)'s Advanced Studies of Climate Change Projection initiative and JMA's Meteorological Research Institute assessed the influences of global warming using an event attribution (EA) approach (Table 5-1), with the following results:
  - ✓ The record-high temperatures observed around Japan in summer 2025 would virtually never have happened with the assumption of no effects from global warming.
  - ✓ Such high-temperature events can be expected to occur once every 60 years in the climate conditions of 2025 with global warming.
  - ✓ The heavy rainfall observed around Kumamoto in Kyushu region from 10 to 11 August was approximately 25% greater with current climate conditions than with theoretical experimental conditions assuming no global warming.
- The rate of temperature increase experienced under global warming has accelerated in recent years.
  - ✓ Record-high summer mean surface air temperatures over Japan have been observed in three consecutive years (2023 to 2025), far exceeding the projected linear trend of temperatures based on the period from 1995 to 2024.
  - ✓ Although there is still no unified view, recent studies have reported that the increase in the rate of temperature rise is attributable to some factors such as interdecadal-timescale atmospheric and oceanographic variability and reduced air pollution.

Table 5-1 Expected frequency of temperatures observed in 2025 (EA approach)

Period	Expected frequency of temperatures exceeding 2025 levels	
	July	**Summer (June – August)**
Pre-industrial	Negligible	Negligible
Normal (1991 – 2020)	Approx. once every 420 years	Approx. once every 500 years
2025 (error margin)	Approx. once every 70 years (from 30 to 100 years)	Approx. once every in 60 years (from 30 to 180 years)

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Figure A Climatological regions of Japan