Climate characteristics and factors behind record-high temperatures in late June/early July 2022 and subsequent weather conditions

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https://www.data.jma.go.jp/tcc/tcc/

Summary

- The seasonal temperature in summer of 2022 was higher than normal across Japan. Especially the period from late June to early July was characterized by record high temperatures recorded in eastern and western parts of the country (Figure A1). Heavy rain occurred in many areas in mid-July. From late July to mid-August northern Japan also experienced heavy rain, and high temperatures were observed in western Japan and elsewhere.
- The conditions observed are mainly attributed to the following:
  - The record-high temperatures observed in late June and early July are attributed to the meandering northward of the upper-level subtropical jet stream (STJ) near Japan and a record strengthening of both the upper-level high and the Pacific High at the surface for this time of year, combined with a persistent warming trend.
  - Factors contributing to the subsequent heavy rainfall in various areas in mid-July include a persistent blocking high over northern Japan and a meandering of the STJ southward near Japan, which made the area susceptible to upper-level cold air.
  - From late July to mid-August, the STJ moved northward and tended to maintain a front near northern Japan that produced heavy rainfall, while high temperatures persisted in western Japan and elsewhere.

1. Climate characteristics and factors behind record high temperatures in late June and early July

(1) Characteristics of high temperatures and climate conditions

In late June, the northward extension of the Pacific High at the surface strengthened and the Baiu front moved northward, resulting in record-high temperatures in eastern Japan (+4.0°C above the normal), western Japan (+3.2°C) and elsewhere (Figure 1-1). Northern Japan observed the second-highest temperatures on record (+2.9°C above the normal).

Also in late June and early July, 24 of the 914 stations in Japan observed record-high temperatures. In particular, Isesaki in Gunma Prefecture recorded daily maxima above 40°C on June 25/29 and July 1, and Tokyo also observed daily maxima above 35°C for a record nine consecutive days from June 25 onward. Figure 1-2 shows the cumulative number of extremely hot days (with daily maximum temperatures above 35°C) observed at AMeDAS stations nationwide from June 1 to August 31. The top three years with the highest average summer temperatures (2010, 2013 and 2018) are shown for comparison. During the same period for 2022, the cumulative number of such stations increased significantly and earlier than in the aforementioned three years.

To identify possible causative factors, JMA, with the TCC Advisory Panel on Extreme Climatic Events (a JMA body staffed by prominent experts on climate science from universities and research institutes), investigated factors considered to have contributed to these extreme climatic conditions.

(2) Characteristics of large-scale atmospheric circulation causing record-high temperatures

This section describes the characteristics of the large-scale atmospheric circulation that caused the record-high temperatures of late June/early July and factors contributing to the phenomenon (Figure 1-3). The circled numbers correspond to those in Figure 1-3.

- Near Japan, both the Pacific High at the surface (①) and the upper-level high (②) were significantly strengthened for this time of year (Figure 1-4). A tall anticyclone characterized by warm air covered the area around Japan, and enhanced solar radiation associated with strong downdrafts and persistent stable clear skies brought warm conditions to the region. Combined with the influence of localized over-mountain air currents, this resulted in record-high temperatures exceeding 40°C in some areas.
- The strengthened extension of the upper-level anticyclone toward Japan and the Pacific High at the surface were influenced by the continued significant northward meandering of the upper-level sub-tropical jet (STJ) near Japan (③).
  - ➢ The STJ continued to meander significantly from Eurasia to the seas east of Japan, forming a warm and near-equivalent barotropic anticyclone near the country. This meander may have been partly caused by a large meander of the jet stream over the North Atlantic to Europe, and its influence extended downstream.
- Extremely enhanced cumulus convective activity near the Philippines from late June onward (④) compared to the normal was also associated with the strengthening of the Pacific High's extension toward Japan (Pacific-Japan (PJ) Pattern[1]).
  - ➢ In addition to higher-than-normal sea surface temperatures in the vicinity of the Philippines, the strengthening of an upper-level anticyclone near Japan (making the

[1] When cumulus convective activity near the Philippines is more active than normal, the low-pressure part of the lower atmosphere (monsoon trough) and associated counterclockwise circulation seen from Southeast Asia to the Philippines during the summer season are stronger than normal, and air rising near the Philippines descends near Japan, strengthening the Pacific High's extension over the country's Honshu mainland.

area more susceptible to upper-level cold air intrusion into the subtropical region to the south of the anticyclone (⑤)), may have contributed to increased cumulus convective activity near the Philippines.

- In addition to the strengthened Pacific High and upper-level anticyclones, a continued rising trend in global temperatures associated with global warming (⑥) and significantly higher tropospheric temperatures in the Northern Hemisphere mid-latitudes since late 2020 (⑦) may have further contributed to the record-high temperatures observed.
  - ➢ Preliminary results from Event Attribution[2], which assesses the impacts of global warming, suggest that the probability of such high temperatures is considerably higher than it would have been in the absence of global warming.
  - ➢ The persistence of high tropospheric temperatures in the mid-latitudes of the Northern Hemisphere is considered to have been influenced by the La Niña event that persisted from summer 2020 to spring 2021 and fall 2021 onward, resulting in lower temperatures in the troposphere over the tropics, while the STJ shifted northward from its normal position throughout the Northern Hemisphere.

２. Weather characteristics and related factors from July to mid-August

(1) Weather features

Weather conditions from July to mid-August showed large intra-seasonal variability. Eastern and western Japan experienced record-high temperatures from late June to early July, while northern Japan also continued its trend of extremely high temperatures from late June onward, with the average in early July being the highest since 1946 (Figure 1-1). Okinawa/Amami also experienced the highest mid-July temperature on record.

Meanwhile, cloudy and rainy conditions from northern to western Japan in mid-July resulted in fewer hours of sunshine and above-normal precipitation amounts. Heavy rainfall with record amounts of short-period precipitation occurred in many areas (Figure 2-1). Precipitation totaling 111.0 mm over one hour and 360.0 mm over six hours was observed at Hatoyama in Saitama Prefecture on July 12, and 191.5 mm over three hours was observed at Mitsushima in Nagasaki Prefecture on July 18, representing new highs for both locations.

The Pacific High extended over mainland Japan again in late July, and the number of stations recording extremely high temperatures (above 35°C) increased (Figure 1-2). From August 3 to 4, a front moved slowly southward over the Tohoku and Hokuriku regions, bringing record-heavy rainfall (Figure 2-2) that caused landslides, river flooding and other issues. Shimoseki in Niigata Prefecture recorded precipitation of 149.0 mm over one hour,

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2 A method for probabilistic estimation of how much the occurrence of individual phenomena has changed due to global warming by comparing a number of simulation experiments conducted under past climate conditions using a climate model and simulations conducted under a scenario with no global warming caused by human activity.

323.5 mm over three hours and 560.0 mm over 24 hours on August 4, all of which were record-highs for the location.

From late to mid-August, a stagnant front persisted near northern Japan. The northern part of Tohoku region experienced record-heavy rainfall, especially in Aomori Prefecture, with total precipitation exceeding 400 mm from August 8 to 14 (Figure 2-3). Due to Tropical Storm (TS) Meari (T2208), the area of heavy rainfall extended to the Tokai and Kanto regions.

(2) Characteristics of large-scale atmospheric circulation

The characteristics of the large-scale atmospheric circulation that produced the weather conditions reported here are detailed below for each period.

(a) Mid-July (Figure 2-4)

- In upper levels, a blocking high formed to the north of Japan in early July and persisted until mid-July. Over Japan to the south of this upper-level high, a cold trough (vortex) persisted, causing unstable atmospheric conditions and contributing to record-heavy short-period rainfall.
  - The formation and persistence of the blocking high to the north of Japan was related to the ongoing large meander of the polar-front jet stream.
  - The persistence of the trough in the upper troposphere near Japan was also influenced by the persistent large meander of the STJ over Eurasia and its ongoing southward shift near Japan. Along with this, the Pacific High at the surface tended to extend westward over the seas south of Japan with a weak extension toward the country’s mainland.
  - The large meander of the STJ over Eurasia may have been influenced by significantly enhanced cumulus convective activity from the southeastern Arabian Peninsula to the area near Pakistan in early July.

(b) Late July – first half of early August

- From late July to early August, the STJ meandered significantly northward near Japan, and the Pacific High again strengthened its extension toward the country’s mainland, resulting in higher-than-normal temperatures over eastern, western and other parts of the nation. TSs Songda (T2205) and Trases (T2206), which successively formed to the south of Japan, moved northward over the East China Sea along the fringe of the Pacific High (Figure 2-5, bottom).
- On August 3 - 4, the northward meander of the STJ weakened, the Pacific High extension was centered over western Japan, and the front moved slowly southward over the Tohoku and Hokuriku regions.

- Warm and moist lower-level air containing large amounts of water vapor associated with these two TSs flowed over the Sea of Japan along the fringe of the Pacific High and over the Tohoku and Hokuriku regions, where the front was stagnant (Figure 2-5, top), contributing to heavy rainfall in these regions. Stationary linear mesoscale convective systems also developed there, resulting in record amounts of precipitation.

(c) Late-early to early-mid August (Figure 2-6)

- While the front remained stagnant from the Sea of Japan to around northern Japan, resulting in record-heavy rainfall in northern Japan, the area from eastern Japan to Okinawa/Amami was often covered by the Pacific High (except when TS Meari (T2208) landed), resulting in higher-than-normal temperatures.
- Around northern Japan, a confluence of moisture inflow along the fringe of the Pacific High and moisture inflow along the frontal zone persisted. These conditions were brought about by the STJ moving northward again over northern Japan, while the upper-level trough meandered southward over Russia's Primorskya Oblast and the Pacific High remained stronger than normal over seas south of Japan.
- The stronger-than-normal STJ flowing northeastward around northern Japan and the front tended to stagnate, while the upper-level trough strengthened upwelling and enhanced convective precipitation activity around the front, which may have been a factor behind the heavy rainfall.
- The significant meandering of the STJ over Eurasia and the strengthened westward-extended Pacific High to the south of Japan may have been influenced by enhanced cumulus convective activity from the northern Indian Ocean to the South China Sea.
  - ➢ The enhanced cumulus convective activity in the region is thought to have enhanced the meandering of the STJ over Eurasia, which further affected the area around Japan.
  - ➢ In addition, lower-level winds blew toward the region of active cumulus convection, and the influence of suppressed cumulus convective activity due to the predominance of downwelling over seas south of Japan is thought to have strengthened the westward extension of the Pacific High.

(d) Effects of global warming on precipitation

Japan exhibits a long-term trend of increasing intensity in extremely heavy rainfall, with the annual maximum 72-hour precipitation at AMeDAS stations showing an upward trend of around 10% over the past 30 years (Figure 2-7). One background factor to this is the amount of water vapor in the atmosphere, which has shown a long-term rise along with temperature in association with global warming (Figure 2-8). An increase of 1°C in air temperature is known to theoretically increase saturated water vapor content by around 7%.

Further research on heavy rainfall probability and other variables is required for full quantitative evaluation in the field. However, it can be considered that the long-term increase in atmospheric water vapor associated with global warming may have been a factor in the heavy summer rainfall.

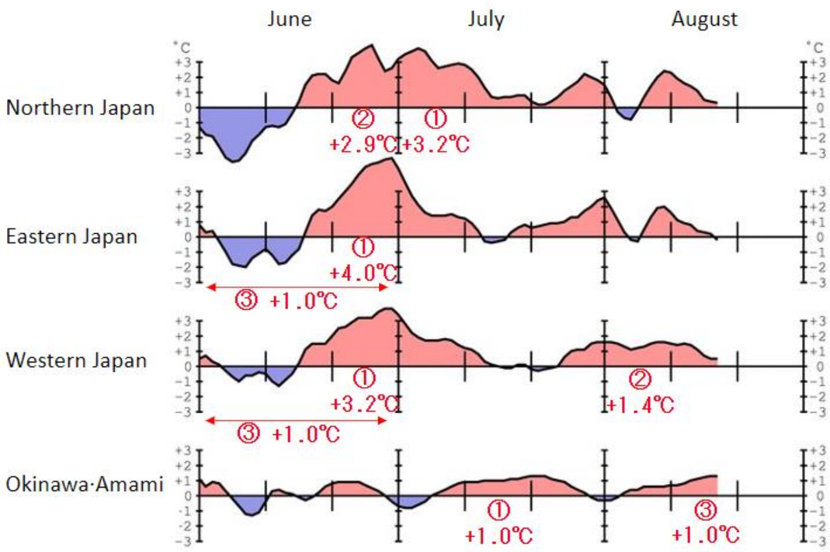

Figure 1-1. Time-series representations of 5-day running mean temperature anomalies [°C] for June-August 2022

The base period for the normal is 1991 - 2020. The red circled numbers and values indicate the rank from highest average temperatures since 1946 and anomalies for each month and each ten-day period (up to the top three).

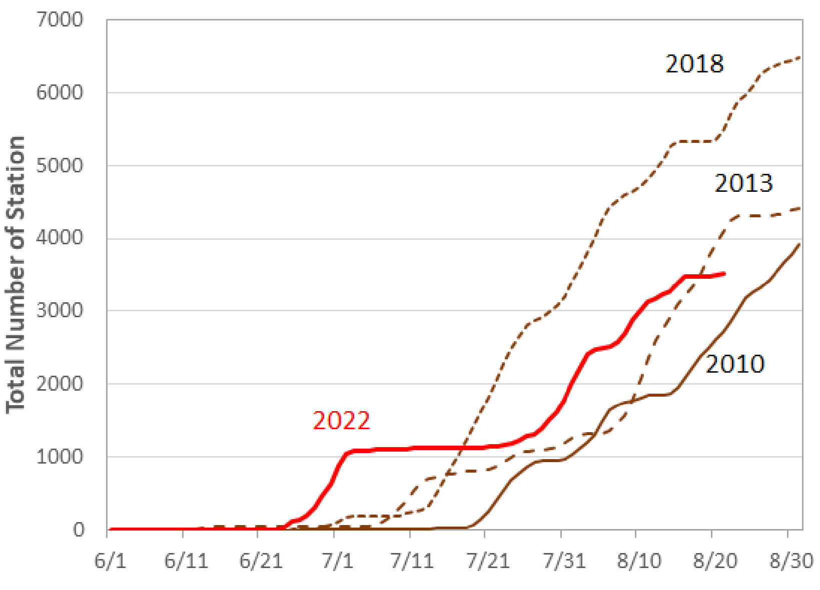

Figure 1-2. Cumulative numbers of extremely hot days (daily maximum temperatures above 35°C) observed at AMeDAS stations nationwide

Results for June 1 - August 31 (red line: 2022 up to August 21) and previous hot years (2010, 2013 and 2018). The total number of AMeDAS stations as of June 1 was 919 for 2010, 927 for 2013 and 2018, and 914 for 2022.

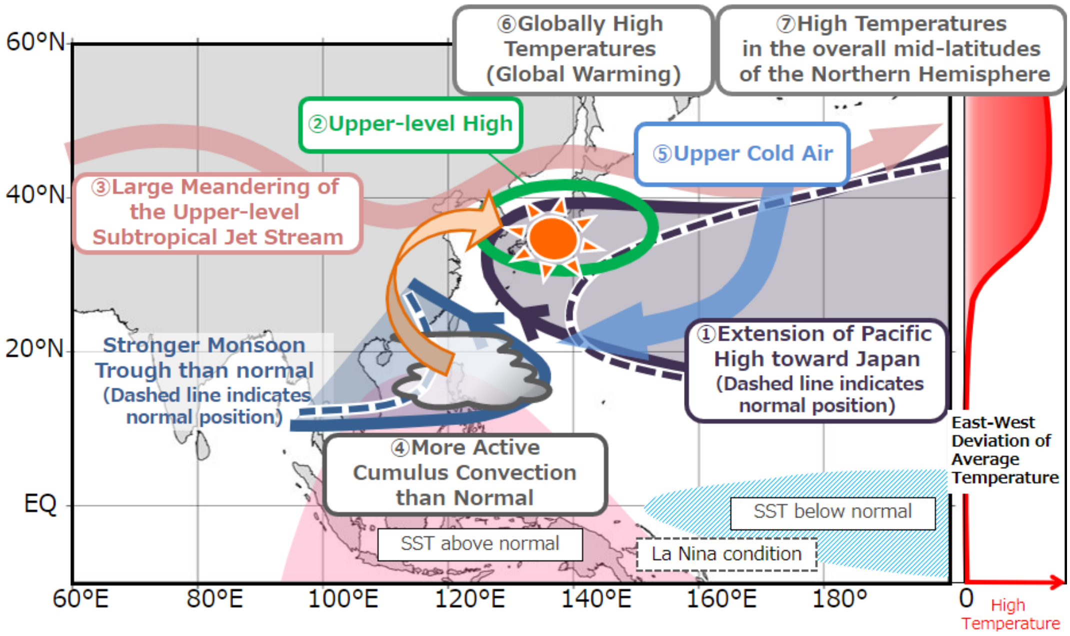

Figure 1-3. Characteristics of atmospheric circulation bringing record-high temperatures in late June and early July

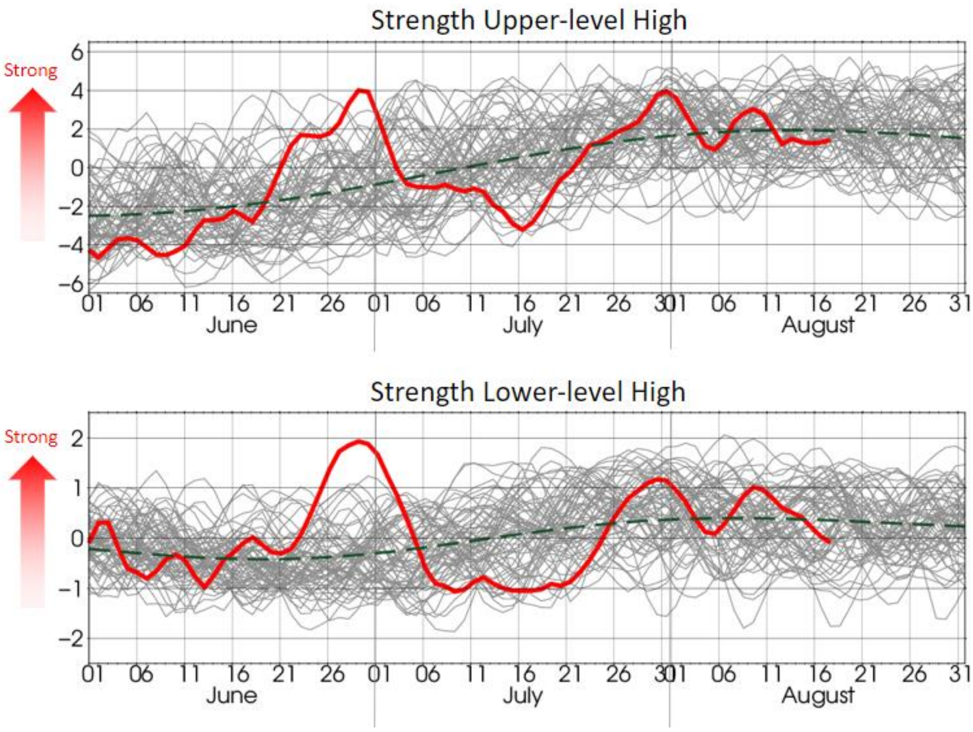

Figure 1-4. Trends in yearly intensity of high pressure around Japan (June 1 – August 31)

The upper panel shows the five-day running average of anticyclone intensity (sign-reversed relative vorticity; unit: $10^{-4}s^{-1}$) in the upper troposphere (around 12,000 m altitude) averaged from 35 to 45°N and 125 to 150°E, and the lower panel shows the lower troposphere (around 1,500 m altitude) averaged from 30 to 40°N and 125 to 150°E. The red line represents 2022 (until August 20), the green dashed line represents the normal (1991 – 2020 average), and the grey lines represent the years from 1958 to 2021, with larger values indicating stronger anticyclones. Data are based on the Japanese 55-year Reanalysis (JRA-55).

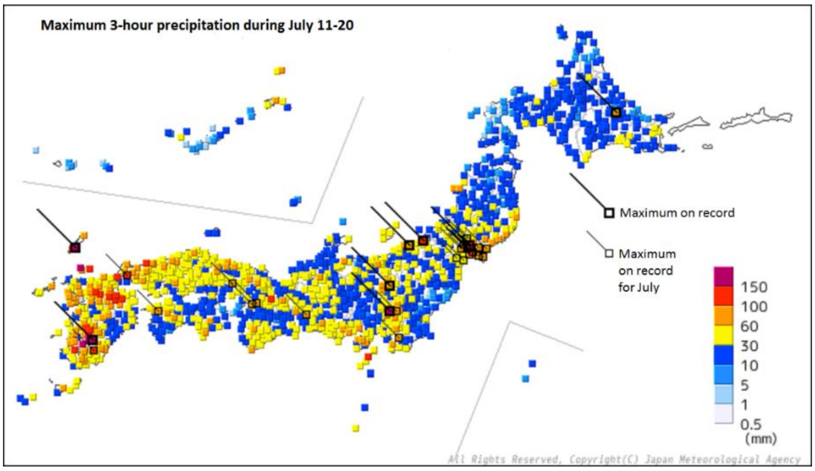

Figure 2-1. Maximum 3-hour precipitation during July 11-20

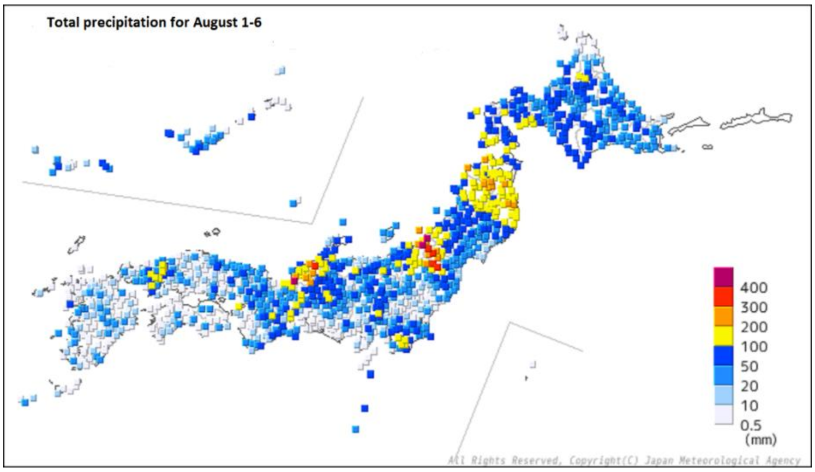

Figure 2-2. Total precipitation for August 1 - 6
Record breaking status is not shown.

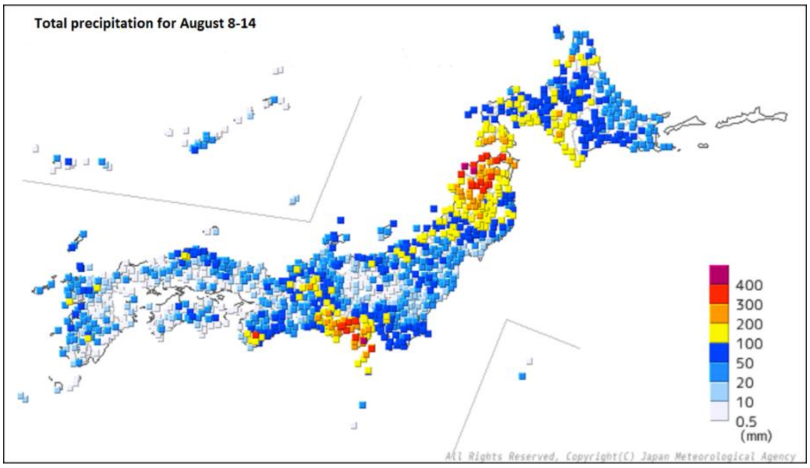

Figure 2-3. Total precipitation for August 8 - 14
Record breaking status is not shown.

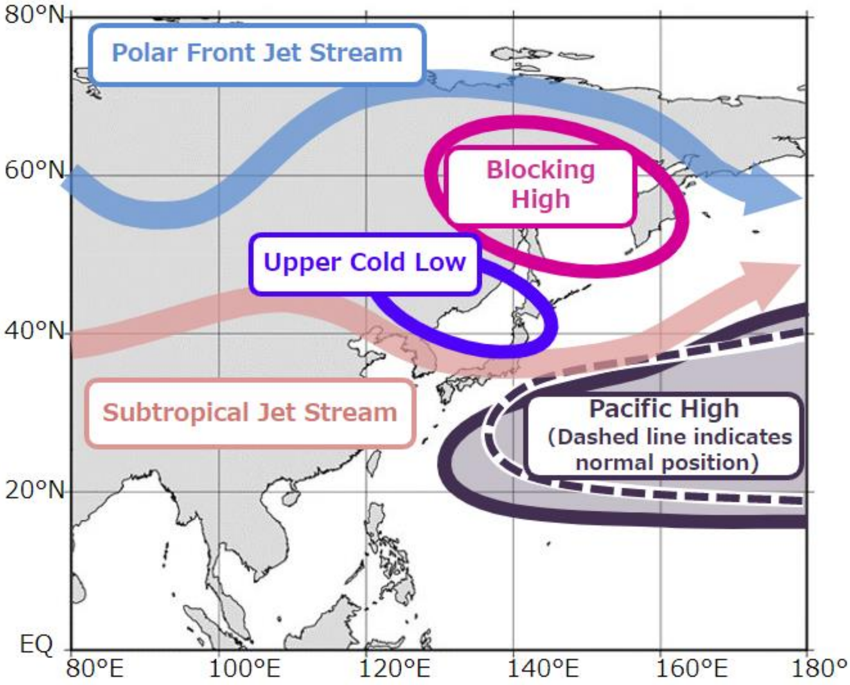

Figure 2-4. Characteristics atmospheric circulation bringing the unusual weather conditions in mid-July

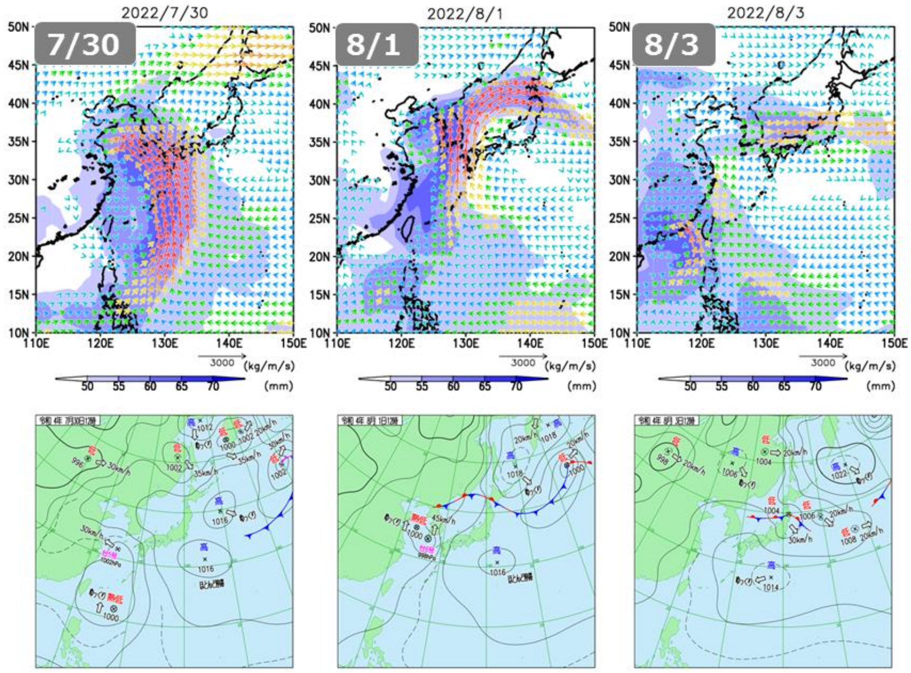

Figure 2-5. Water vapor flow and surface weather maps for July 30, August 1, and August 3

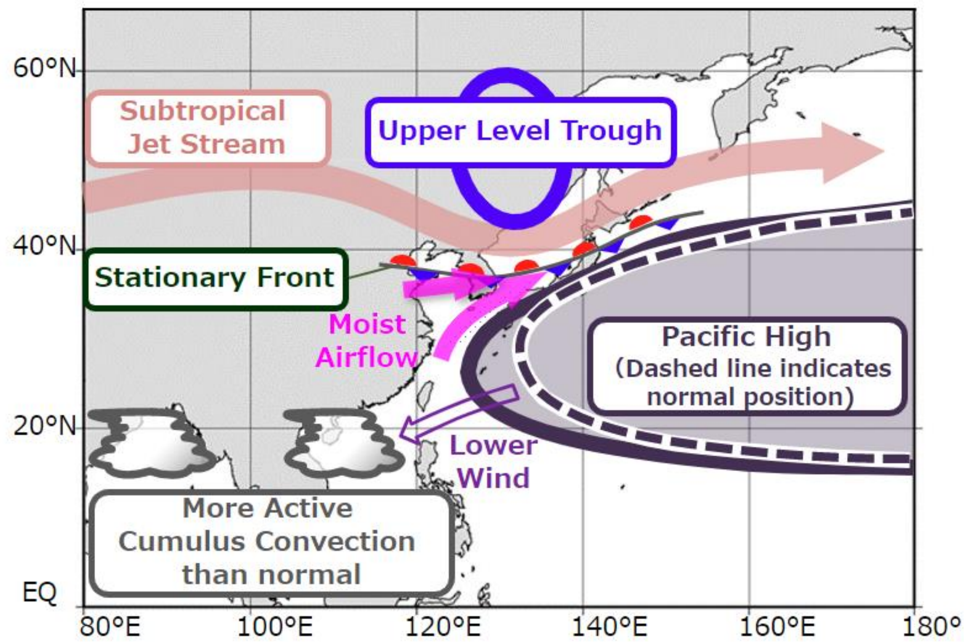

Figure 2-6. Characteristics of atmospheric circulation bringing heavy rainfall centered over northern Japan in late-early to early-mid August

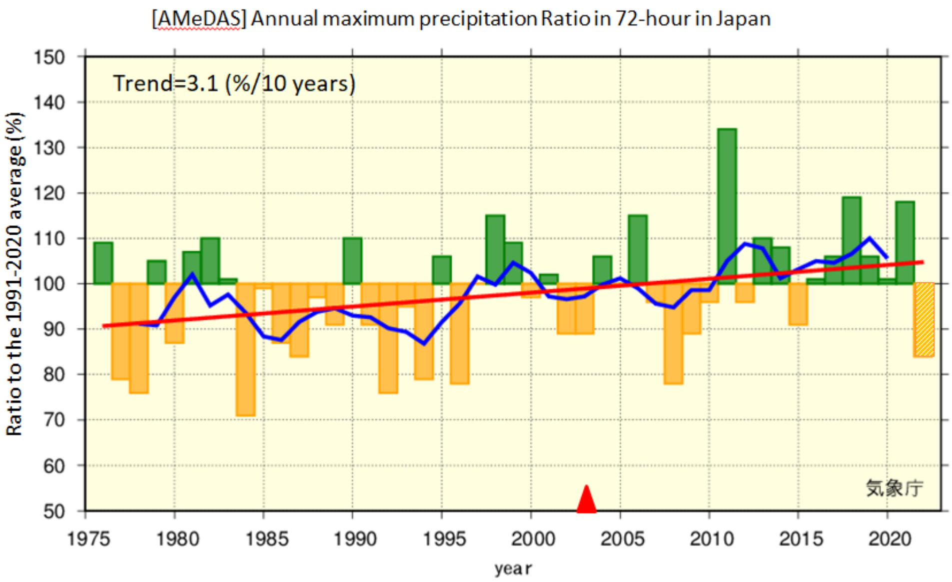

Figure 2-7. Annual maximum precipitation ratios in 72 hours from 1976 to 2022 in Japan
This graph is based on precipitation data from 637 AMeDAS stations which have been continuously operated from 1976 to 2022. Bars indicate the ratio to the baseline (the 1991–2020 average), while the blue and red lines indicate the related five-year running mean and the long-term linear trend, respectively (statistically significant at a confidence level of 95%). The value for 2022 is preliminary as of August 21. The red triangle marks the timing of a change in the observation method for precipitation (observed every hour before 2003 and every 10 minutes thereafter).

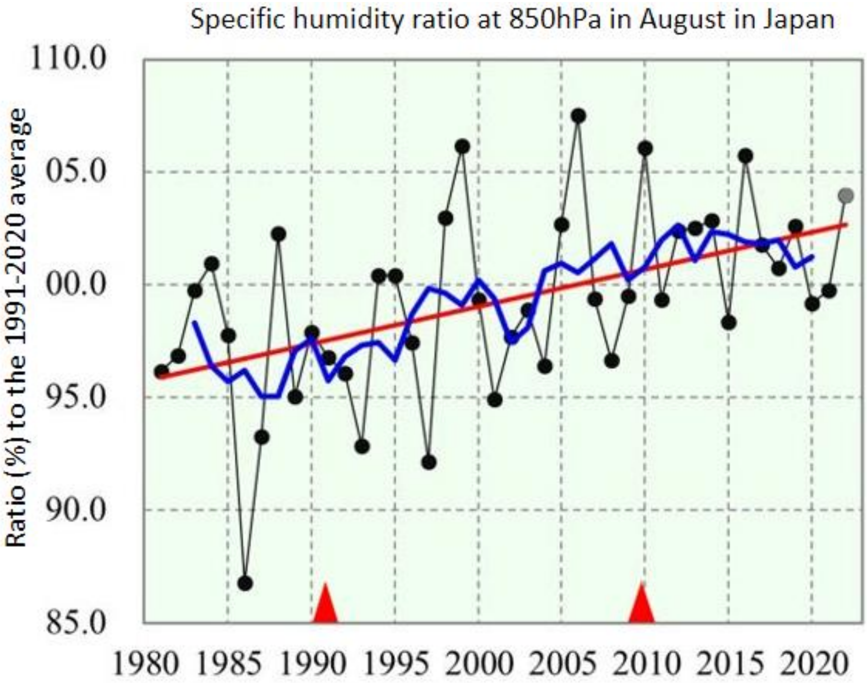

Figure 2-8. Specific humidity ratio at 850hPa for August from 1981 to 2022 over Japan
The data are presented as ratios against the baseline (the 1991 –2020 average).
Note: The term specific humidity refers to the mass of water vapor in a unit mass of moist air (g/kg). The data used in this analysis were based on radiosonde observations (balloon-borne instrument platforms with a radio-transmitting device) at 13upper-air observation stations in Japan (Wakkanai, Sapporo, Akita, Wajima, Tateno, Hachijojima, Shionomisaki, Fukuoka, Kagoshima, Naze, Ishigakijima, Minamidaitojima, and Chichijima). The values for 2022 are based on data through August 20. The thin black line indicates the averages of the data for the 13stations. The blue and red lines indicate the related five-year running mean and the long-term linear trend, respectively(statistically significant at a confidence level of 99%). Data from the period marked by the red triangles may include biases due to instrument changes.

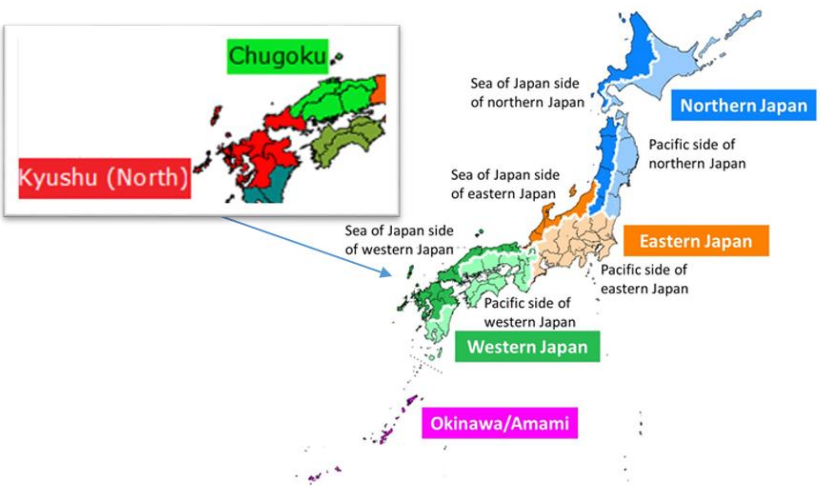

Figure A1. Climatological regions of Japan
JMA's seven regional divisions for climate monitoring and forecasting (the Sea of Japan and Pacific sides of northern, eastern and western Japan, and Okinawa/Amami)