Climate characteristics and factors behind record-heavy rain in Japan in August 2021

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

Summary

- In mid-August 2021, areas from western to eastern Japan experienced record-heavy rain.
- The conditions observed are mainly attributed to the following:
  - Unusually for mid-summer in eastern and western Japan, like atmospheric flow in the latter half of the early-summer rainy season, known as the Baiu, a stationary front was strengthened by a significant north-south gradient of temperature in the lower troposphere between the Okhotsk High to north of Japan and the southward shifted North Pacific Subtropical High (NPSH) expanding to the south of Japan. A continuous confluence of water vapor from continental China and along the margin of the NPSH also contributed to widespread continuous heavy rainfall.
  - The southward shift of the NPSH that caused a large amount of water vapor flow into western and eastern Japan was related to the subtropical jet stream (STJ) in the upper troposphere, with an overall southward shift over East Asia. Furthermore, significant southward meandering of STJ to the west of Japan is considered to produce a favorable conditions for updraft occurrence and persistent rainfall.
  - The southward shift of the STJ was likely affected by sea surface temperatures (SSTs) in the tropical Indian Ocean and related convective activity over the Asian summer monsoon region.
- On 14th August, the northern part of the Kyushu region (see Figure A1 for the locations) experienced extremely heavy rainfall associated with stationary linear mesoscale convective systems. In addition to the formation of conditions conducive to convective cloud development to the south of the front a small-scale low was also developed on the same day on the front over the East China Sea. This may have contributed to the formation of cumulonimbus clouds organized as stationary linear mesoscale convective systems over sea areas west of the Kyushu region to the east of the small-scale low.

1. <u>Climate conditions</u>

Wide areas from western to eastern parts of Japan experienced record-heavy rainfall totaling as much as 1,400 mm from mid- to late August 2021 in association with a highly active stationary front over the country (Figure 1-1, 1-2, 1-3, 1-4 and Table 1-1). From 12th to 14th August in particular, stationary linear mesoscale convective systems contributed to these conditions over the northern Kyushu and Chugoku regions (see Figure A1 for the locations of these regions), with JMA issuing Emergency Warnings for various locations from 13th to 15th August. Monthly precipitation on the Sea of Japan and Pacific sides of western Japan was the highest on record for August since 1946, when collection of the area-averaged statistical data referenced here began (Table 1-2).

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. Factors

The primary factors contributing to the climate conditions detailed above are illustrated in Figure 2-1.

The widespread heavy rainfall event was partially attributed to unusual frontal formation for midsummer[1] in eastern and western Japan, like atmospheric flow in the latter half of the early-summer rainy season, known as the Baiu, relating to a significant gradient of north-south temperature in the lower troposphere between the Okhotsk High in northern Japan and the NPSH in the south. The cold Okhotsk High on the surface developed from early August onward and persisted due to an evolved blocking high over eastern Siberia in the upper troposphere. The NPSH shifted farther southward than normal and expanded to the seas south of Japan. Continuous and massive inflow of water vapor into the front from continental China and along the margin of the NPSH also contributed to the event (Figure 1-5).

The southward shift of the NPSH that caused a large amount of water vapor flow into western and eastern Japan was related to the southward shift of the subtropical jet stream (STJ) from East Asia to Japan in the upper troposphere. Furthermore, significant southward meandering of the jet stream to the west of Japan is considered to have supported upward airflow and persistent rainfall over areas from eastern to western Japan.

From mid-July to early August, tropical SSTs were higher than normal to the southwest of Sumatra and lower than normal in the western part of the Indian Ocean. In association, the Asian summer monsoon was less active than normal from the South China Sea to the area east of the Philippines, and its active convection region was shifted southwest of its normal position.

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[1] The North Pacific Subtropical High normally extends northwestward around Japan, bringing hot and sunny conditions to the country in mid-summer.

Statistical analysis indicates that the inactive and southwestern-biased Asian monsoon may have caused the STJ over East Asia to shift southward overall and meander southward to the west of Japan.

3. Characteristics of the record-heavy rain event and related atmospheric conditions

From August 12th to 14th, the Chugoku region and the northern part of the Kyushu region experienced stationary linear mesoscale convective systems and JMA issued nine instances of Bulletin on Significant Heavy Rain (Table 3-1). Before dawn and on the morning on 14th August in particular, the northern part of the Kyushu region affected by the stationary linear mesoscale convective systems experienced extreme heavy rainfall (Figure 3-1). During this period, large amounts of water vapor flowed into areas around the front over seas west of the Kyushu region. Along with enhanced updraft near the front, lower-level winds were strengthened to the south of the front, supporting local development of convective clouds (Figure 3-2). On the front over the East China Sea, a small-scale low may also have contributed to the formation of the stationary linear mesoscale convective systems over seas west of the Kyushu region to the east of the small-scale low (Figure 3-3).

The increased precipitation of this event may be linked to a rising long-term trend in airborne water vapor associated with global warming (Figure 2-2 and 2-3), although further studies are needed to evaluate the link quantitatively including probability of heavy rainfall.

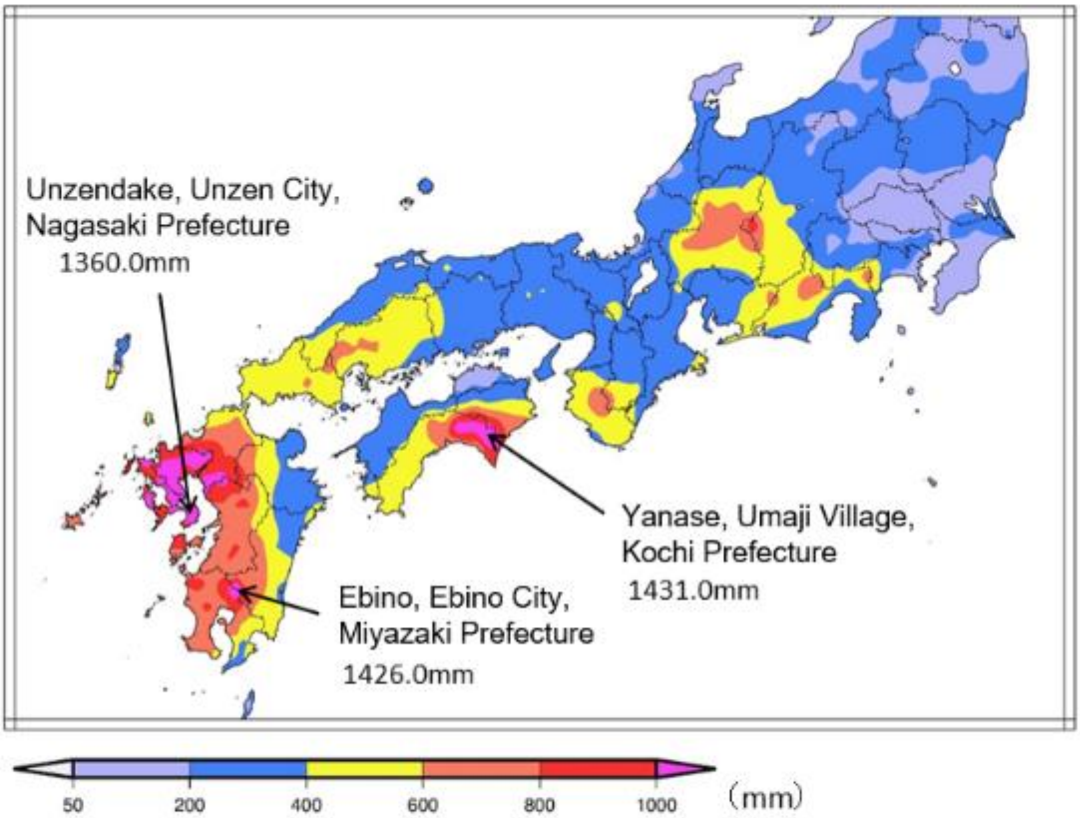


Figure 1-1. Total precipitation amounts [mm] for 11 – 26 August, 2021

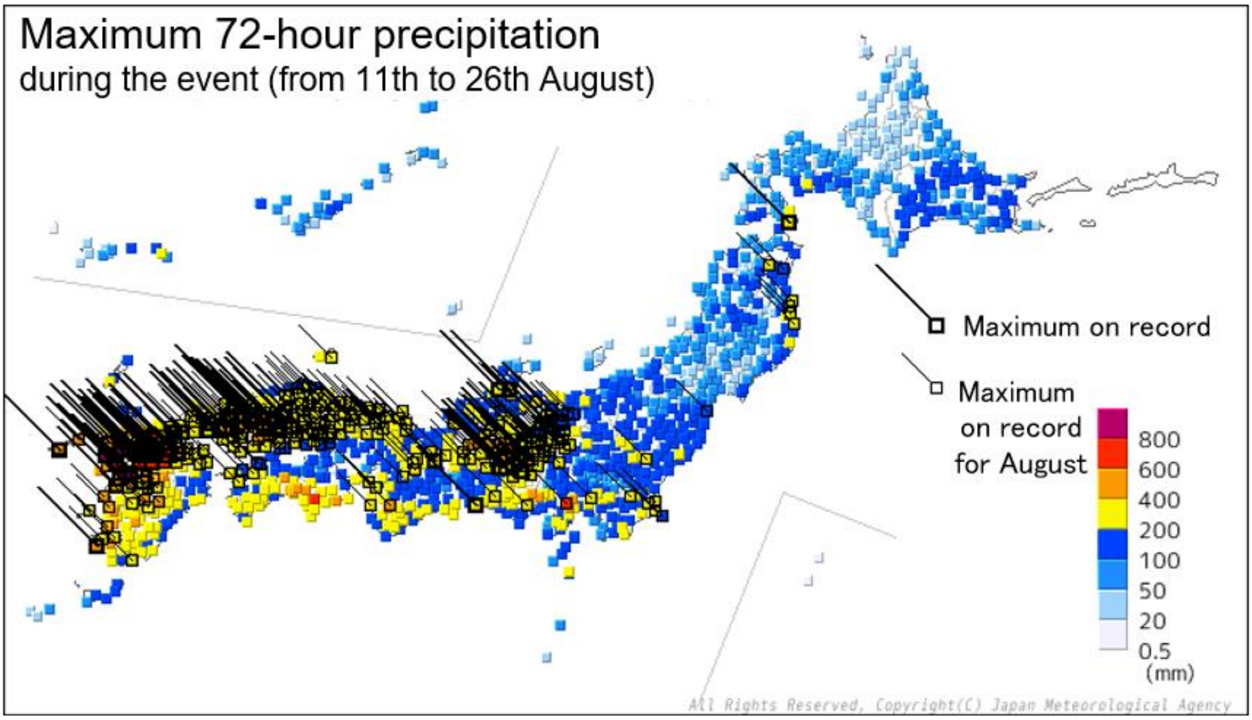


Figure 1-2. Maximum 72-hour precipitation [mm] for 11– 26 August, 2021

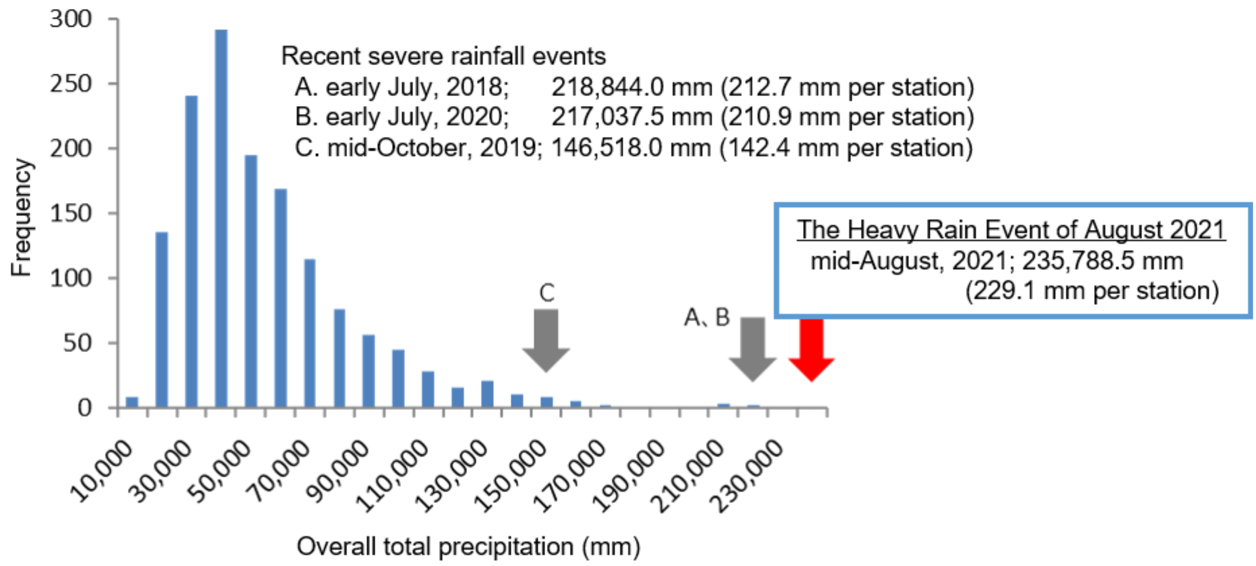


Figure 1-3. Frequency distribution of overall total precipitation at 1029 selected AMeDAS stations throughout Japan for 10-day periods starting on the 1st, 11th and 21st of the month since 1982

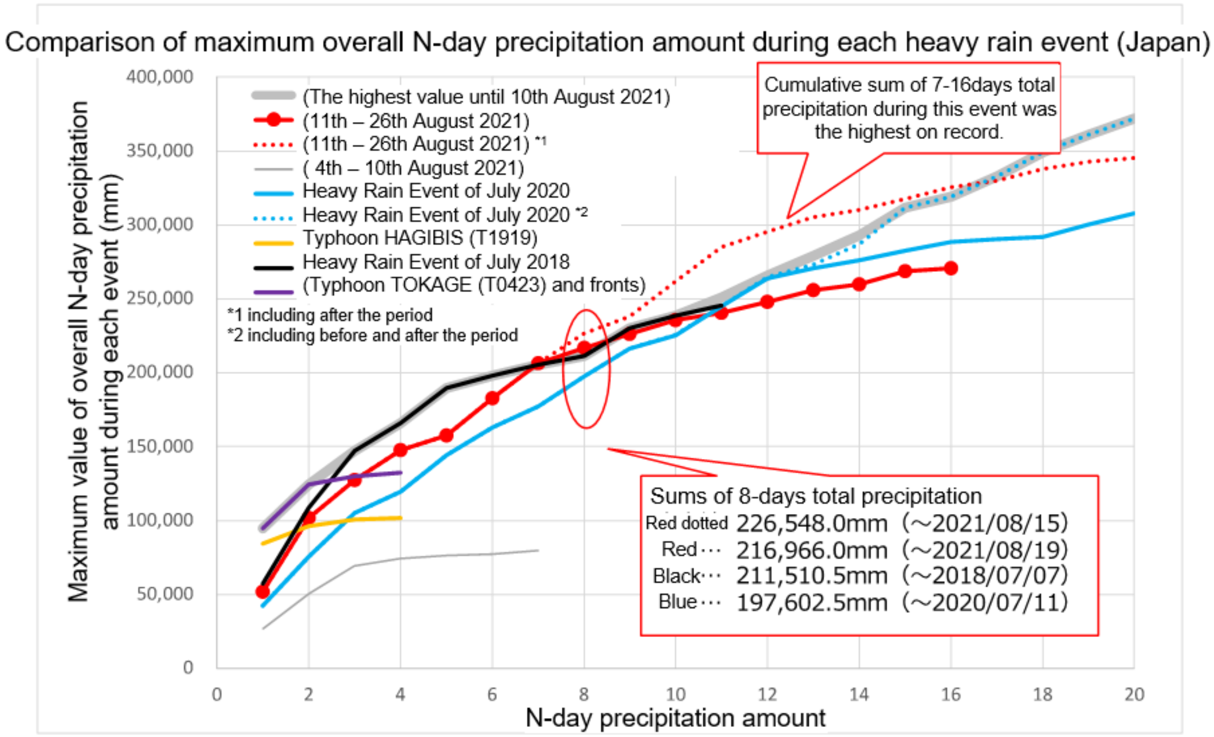


Figure 1-4. Comparison of maximum overall N-day precipitation amount during each heavy rain event occurrence at 1,029 selected AMeDAS stations throughout Japan since 1982

Table 1-1 Record overall total precipitation at selected 1029 AMeDAS stations all over Japan for any 10 days starting from 1st, 11th and 21st of the months since 1982

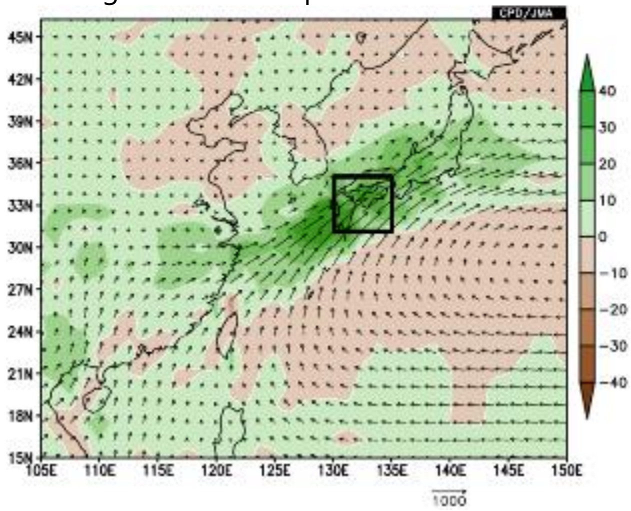
Rank	Period	All stations (mm)
1	Mid-August, 2021	235,788.5
2	Early July, 2018	218,844.0
3	Early July, 2020	217,037.5
4	Late June, 1985	209,016.0
5	Mid-September, 1990	205,925.0
6	Late October, 2017	203,475.5
7	Early August, 2014	185,173.0
8	Late June, 1999	170,692.0
9	Early July, 1995	166,014.0
10	Early September, 1989	165,200.0

Table 1-2 Years and its ratios of the top three highest events of monthly precipitation totals in August from 1946 to 2021

	Western Japan	Sea of Japan side of western Japan	Pacific side of western Japan	Eastern Japan	Pacific side of eastern Japan
1st	**2021(331%)**	**2021(371%)**	**2021(297%)**	1982(208%)	1982(231%)
2nd	2014(246%)	1980(255%)	2014(275%)	**2021(205%)**	**2021(219%)**
3rd	1980(230%)	1993(228%)	2004(216%)	2003(201%)	2003(218%)

Ratios are deviations from the baseline (the 1991 – 2020 average). The rainfall in the Sea of Japan side of eastern Japan in August 2021 was the ninth highest (152% of normal).

(a) Vertical integrated water vapor flux amount and its convergence



(b) Water vapor amounts concentrated in western Japan

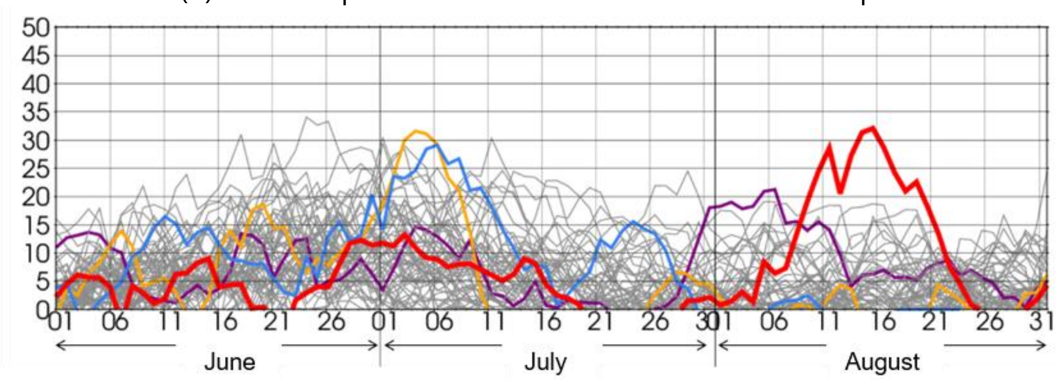


Figure 1-5. (a) Vertically integrated horizontal water vapor flux amount (vectors) and its convergence (shade) averaged over the period from 11th to 17th August 2021 and (b) time-series representation of vertically integrated water vapor flux amount convergence (the 7-day running mean) in the area surrounded by the black lines in (a)) from June to July after 1958

(a) Unit: kg/m/second for vectors and mm/day for shade.

(b) Unit: mm/day. Data for the period from 1958 to 2021 are overlaid into one calendar year. The red, blue, orange and gray indicate values for 2021, 2020 (The heavy rain event of July 2020), 2018 (The heavy rain event of July 2018), 2014 (The heavy rain event of August 2014) and others after 1958, respectively. (a) and (b) are generated from JRA-55 data (Kobayashi, 2015), and vertical integration here represents integration from the surface to 300hPa.

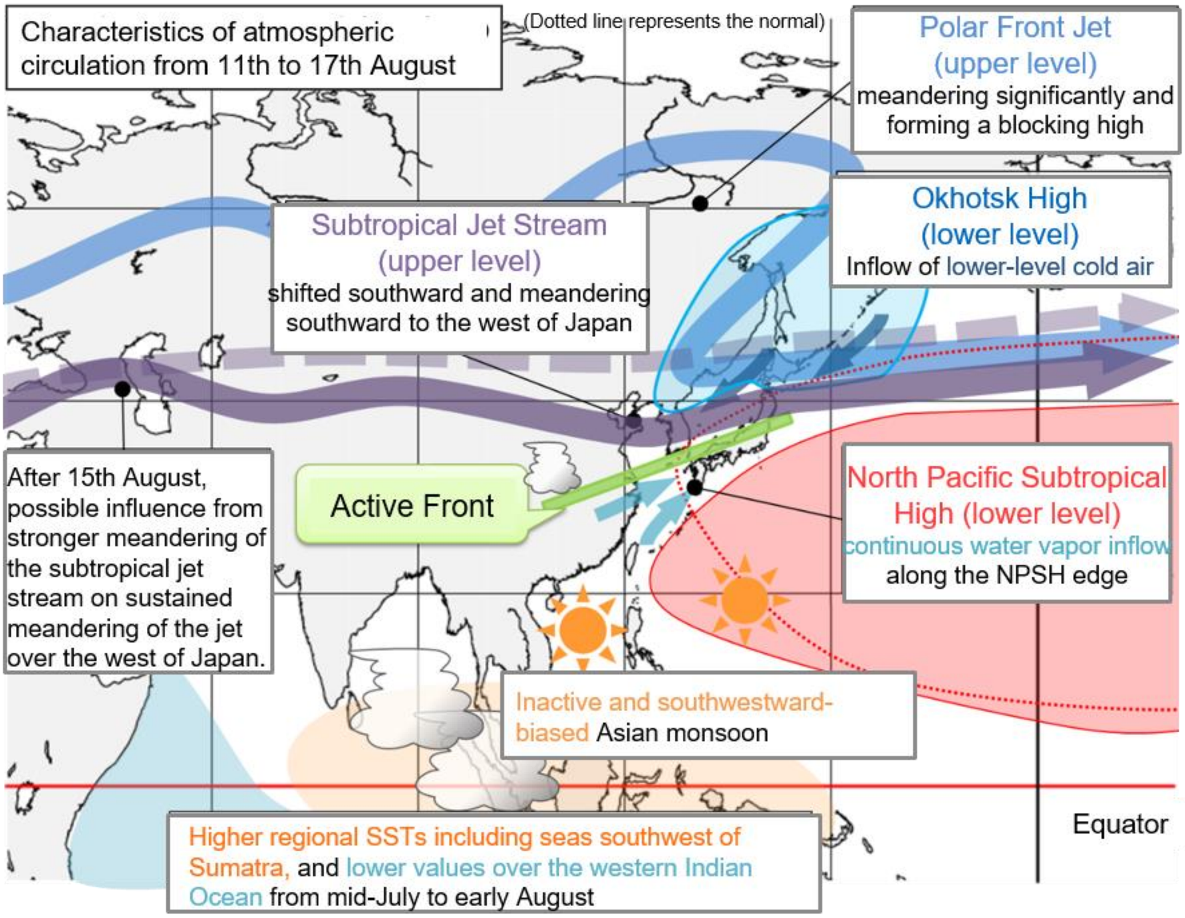


Figure 2-1. Characteristics of atmospheric circulation bringing record-heavy rain from 11th to 17th August

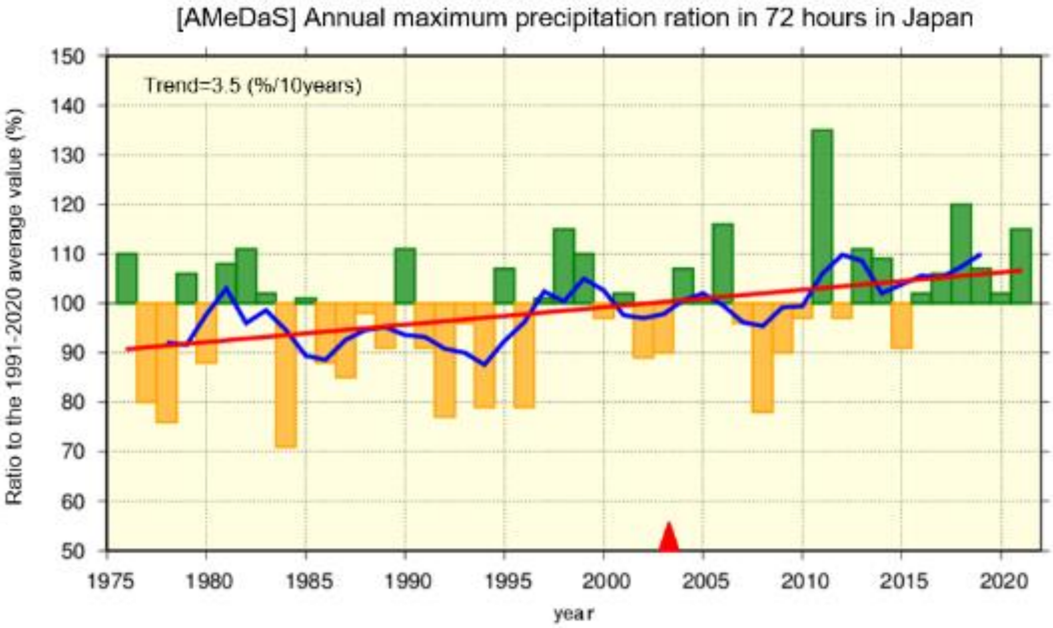


Figure 2-2. Annual maximum precipitation ratio in 72 hours from 1976 to 2021 in Japan

This graph is based on precipitation data from 637 AMeDAS stations which have been continuously operated from 1976 to 2021. 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 2021 is preliminary as of 31st of August. 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).

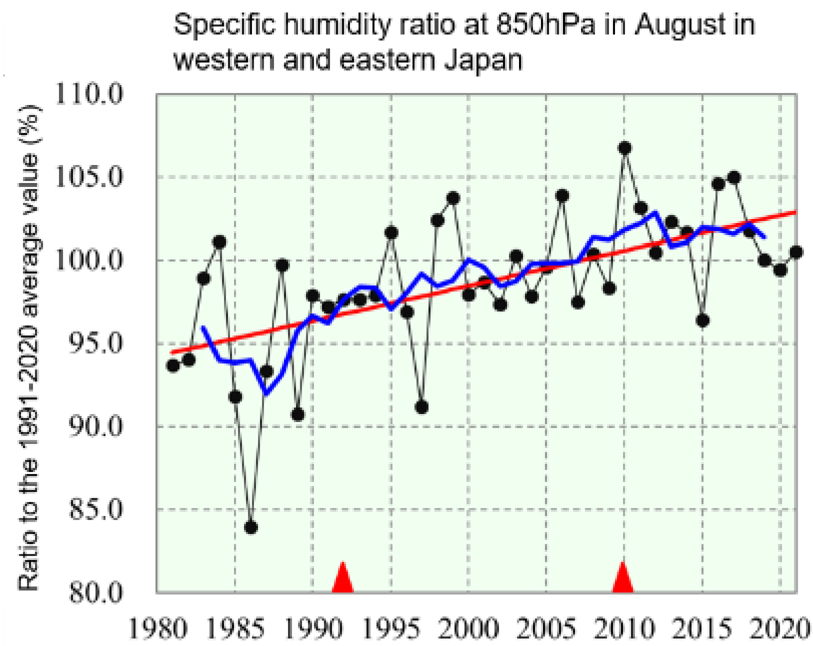


Figure 2-3. Specific humidity ratio at 850 hPa for August from 1981 to 2021 in western and eastern Japan

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 6 upper-air observation stations in western and eastern Japan (Wajima, Tateno, Hachijojima, Shionomisaki, Fukuoka and Kagoshima). The thin black line indicates the averages of the data for the 6 stations. 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.

Table 3-1. Issues regarding bulletin on significant heavy rain in mid-August 2021

Bulletin on significant heavy rain relates to ongoing extreme downpours in particular locations associated with stationary linear mesoscale convective systems. Against a background of increasing disaster risk, the content is issued to outline situations with keywords related to such systems when the following conditions are met:

- 1: Areas in which Radar/Raingauge-Analyzed Precipitation with a spatial resolution of 5 km exceeds 100 mm over 500 km^2 during the preceding three hours.
- 2: The shape of the area extracted by the criterion of 1 is linear (with aspect ratios exceeding 5:2).
- 3: Maximum cumulative precipitation amount during the preceding three hours in 1 exceeds 150 mm.
- 4: Real-time Landslide Risk Map exceeds the criteria for Landslide Alert Information and reaches 80 percent of the threshold of soil rainfall index for Heavy Rain Emergency Warnings, or Real-time Flood Risk Map significantly exceed warning criteria.

Information is re-issued when the related criteria still apply three hours after initial issuance, or within the three-hour period if the target area is expanded.

Time of issuance					Issuance number	Prefecture	Primary subdivision
Year	Month	Day	Hour	Minute			
2021	8	12	13	59	1	Fukuoka	Chikugo
2021	8	12	13	59	1	Kumamoto	Kumamoto
2021	8	13	09	19	1	Hiroshima	Northern, Southern
2021	8	14	02	21	1	Saga	Southern
2021	8	14	02	21	1	Nagasaki	Northern
2021	8	14	02	49	2	Nagasaki	Southern, Northern
2021	8	14	05	00	2	Saga	Southern, Northern
2021	8	14	05	59	3	Nagasaki	Southern, Northern
2021	8	14	06	09	1	Fukuoka	Fukuoka

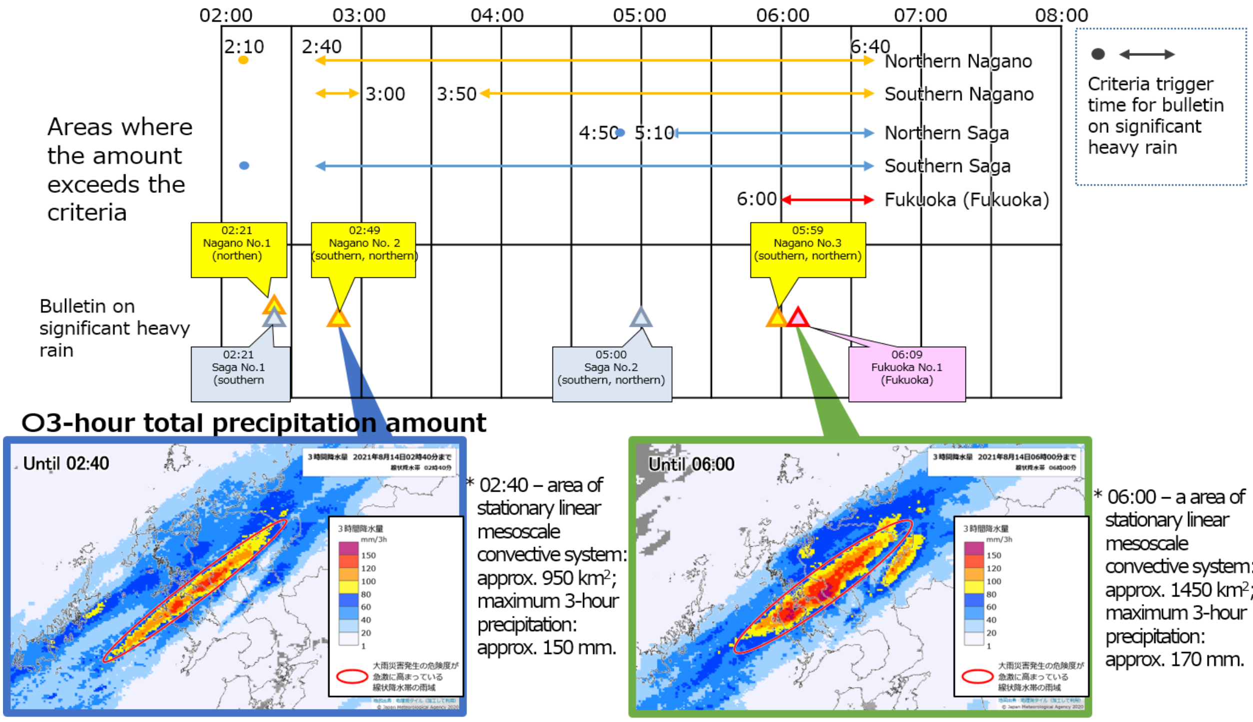


Figure 3-1. Timing of issuance for bulletin on significant heavy rain and related target areas on 14th August

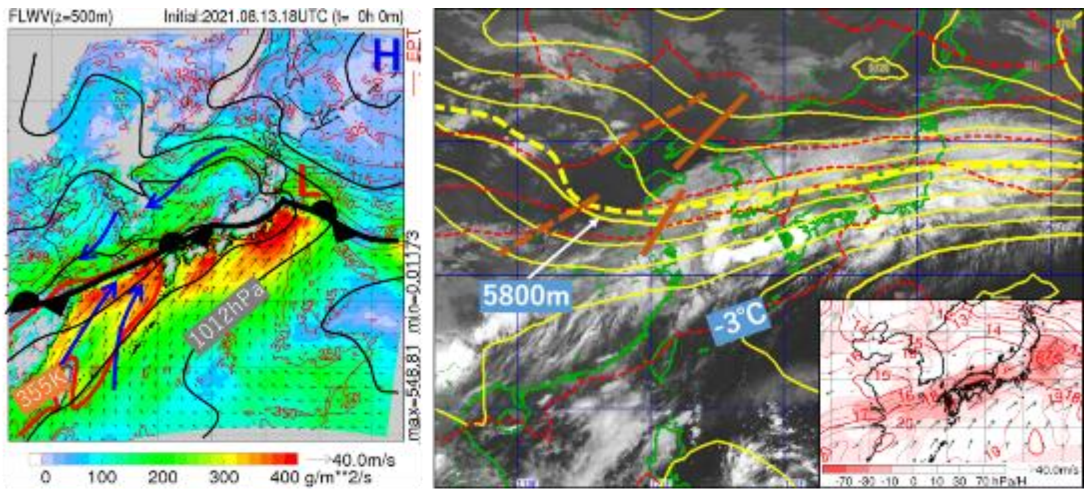


Figure 3-2. Left: 500 m winds (vectors), equivalent potential temperature (red), water vapor flux amount (vectors and shading) and sea level pressure (black) based on JMA meso-scale analysis at 3 a.m. on 14th August 2021 (front and high/low-pressure values from preliminary weather maps). Right: Infrared satellite imagery with 500 hPa geopotential height (yellow) and temperature (red dotted line) for the same time. Lower right: 700-hPa vertical velocity (shade), 850 hPa isotherms (red) and winds (vectors) from the Global Spectral Model (GSM) initial (T = 0). Also shown are 5,800 m isotherms for 12 hours before (yellow dotted line), trough data (brown) and the same for 12 hours before (brown dotted line).

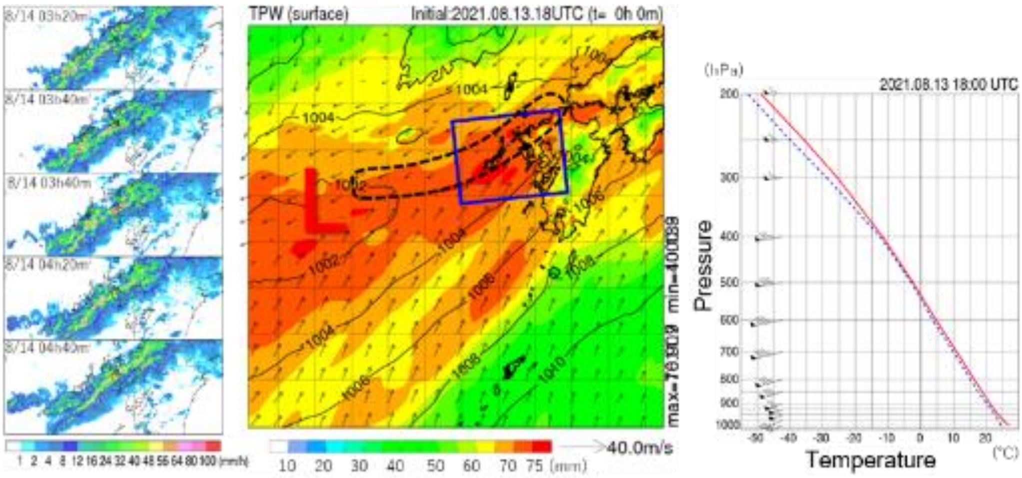


Figure 3-3. Left: Time-series representation of radar echo intensity at 20-minute intervals from 3:20 to 4:40 on 14th August 2021. Center: sea level pressure (black), wind (vectors) and precipitable water (shading) at 3 a.m. on 14th August 2021 based on JMA meso-scale analysis. The black dotted line represents the main convergence area. Right: simultaneous vertical profiles of atmospheric temperature (red) and dew point temperature (blue dotted line) averaged for the area within the blue box in the central figure, based on JMA local analysis.

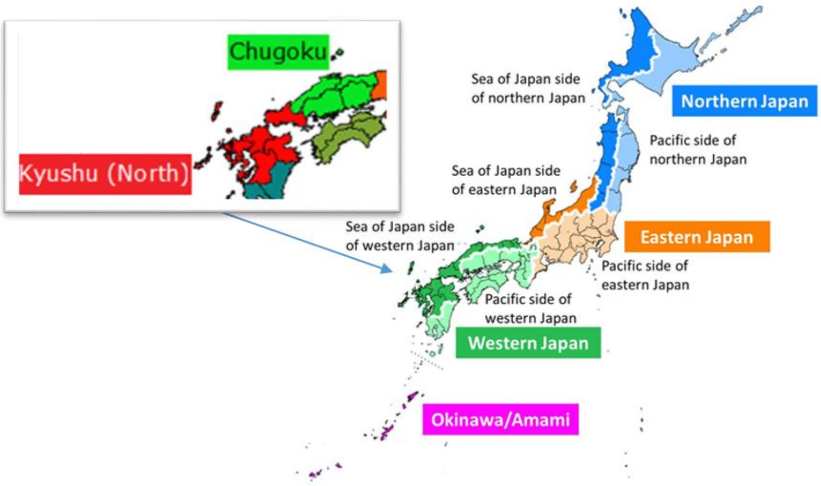


Figure A1. Climatological regions of Japan

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)