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Primary Factors Contributing to Japan's Extremely Hot Summer of 2010

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1. Introduction

Many areas in the world experienced high temperatures for boreal summer (June – August) 2010, especially from western Russia to the Middle East, in northern China, from southern Indonesia to southern Polynesia, and in the eastern USA (Figure 1.1). Japan also experienced nationwide record-breaking high temperature. The seasonal mean temperature in Japan for summer 2010 (*i.e.*, the three-month period from June to August) ousted that of summer 1994 from the top spot as the highest since JMA's records began in 1898, with a deviation of +1.64°C from the 1971 – 2000 average (Figure 1.2). Shortly after this period on 3 September, the Japan Meteorological Agency (JMA) organized an extraordinary meeting of the Advisory Panel on Extreme Climate Events (see Chapter 2 for details). This report summarizes the atmospheric characteristics and possible influences identified by the Advisory Panel as main background factors to Japan's hottest summer on record.

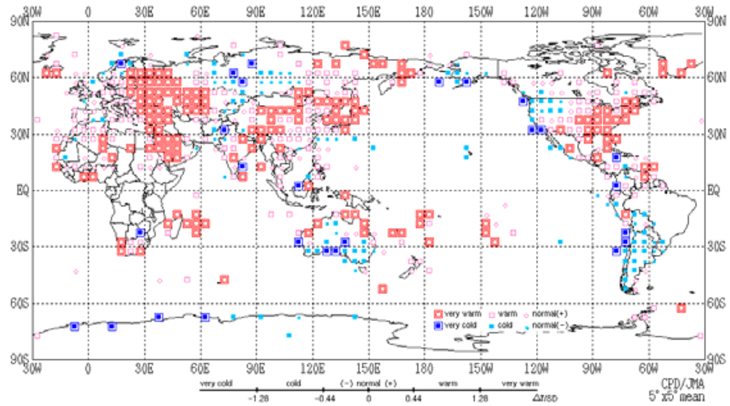

Fig. 1.1 Three-monthly mean temperature anomalies for summer (June – August) 2010. Categories are defined by three-month mean temperature anomaly against the normal (*i.e.*, the 1971 – 2000 average) divided by its standard deviation and averaged in 5° × 5° grid boxes. The thresholds of each category are -1.28, -0.44, 0, +0.44 and +1.28.

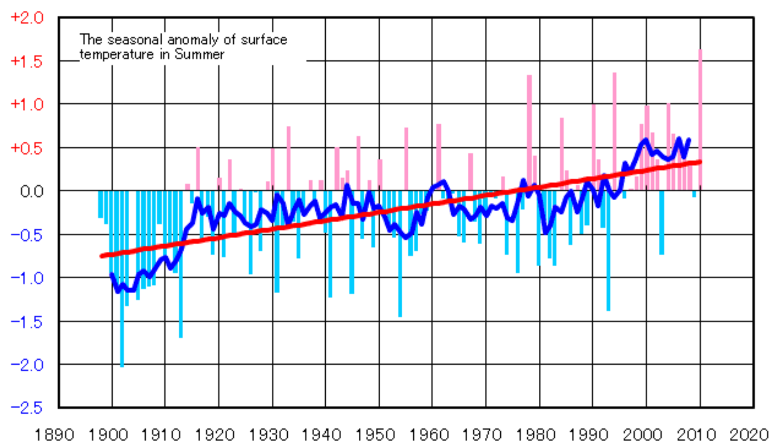

Fig. 1.2 Long-term change in seasonal temperature anomalies for summer (June – August) in Japan. Anomalies are calculated as the average of temperature deviations from the 1971 – 2000 normal at the 17 observation stations. The observatory stations that represent the average temperature of Japan are selected from those deemed to be least influenced by the urban heat island phenomenon. The bars indicate temperature anomalies for each summer. The blue line indicates the five-year running mean, and the red line shows the long-term linear trend.

2. The Advisory Panel on Extreme Climate Events

The Advisory Panel on Extremely Climate Events was established in June 2007 by JMA to investigate extreme climate events based on the latest knowledge and findings and provide JMA with advice on the causes of extreme climate events. Its members are prominent experts on climate science from universities and research institutes. On a regular basis, JMA provides the panel with observational data and monitoring information on climate system. The panel provides JMA with scientific advice on

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climate system monitoring and suggestions on analysis methods. When an extreme climate event occurs or is likely to occur, an extraordinary meeting of the panel is organized to analyze the causes of the event and JMA provides timely statement on the event based on advice from the panel (Figure 2.1).

3. Data source

The datasets used in this analysis are as follows:

1) Surface observational data: JMA's in-site observation.
2) Sea surface temperature (SST) data: the JMA's SST analysis for climate monitoring (COBE-SST) (Ishii *et al.* 2005).
3) Atmospheric circulation data: the Japanese reanalysis (JRA-25/JCDAS) (Onogi *et al.* 2007).
4) Outgoing longwave radiation (OLR) data: original data provided by the National Oceanic and Atmospheric Administration (NOAA).

The base period for normal is 1971 – 2000 for 1) and 2) datasets, and it is 1979 – 2004 for 3) and 4) datasets.

4. Ocean conditions and convective activity in the tropic

In summer 2010, a La Niña event followed the El Niño period that started in summer 2009 and ended in spring (March – May) 2010 (Figure 4.1). In association with this, sea surface temperatures (SSTs) were above normal over the western Pacific, the Indian Ocean and the tropical

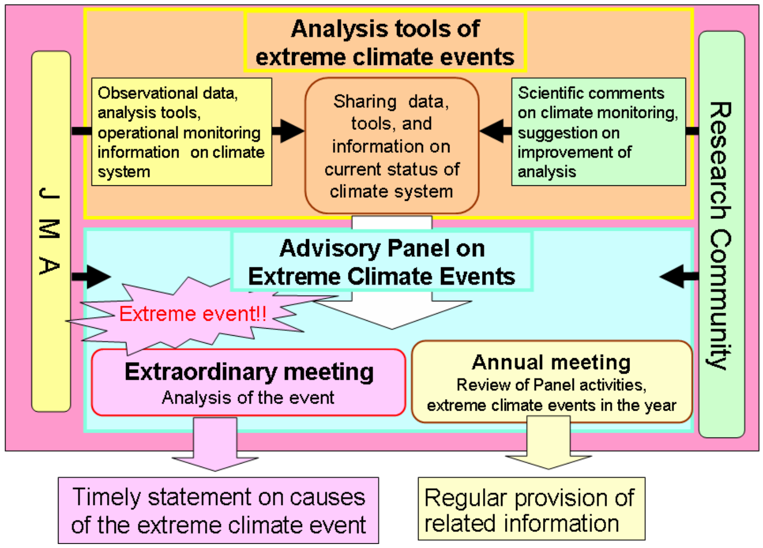

Fig. 2.1 Schematic chart of the framework at the Advisory Panel on Extreme Climate Events.

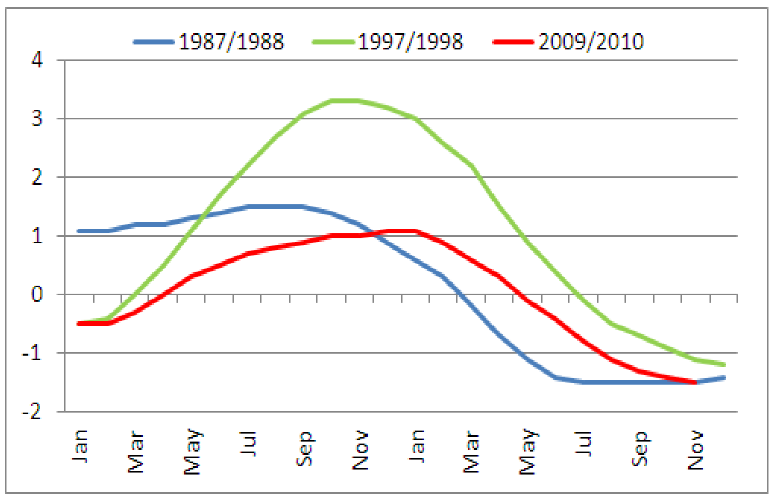

Fig. 4.1 Time series of five-month running mean sea surface temperature deviations (unit: °C) from the climatological mean based on a sliding 30-year period for NINO.3 (5°S – 5°N, 150°W – 90°W).

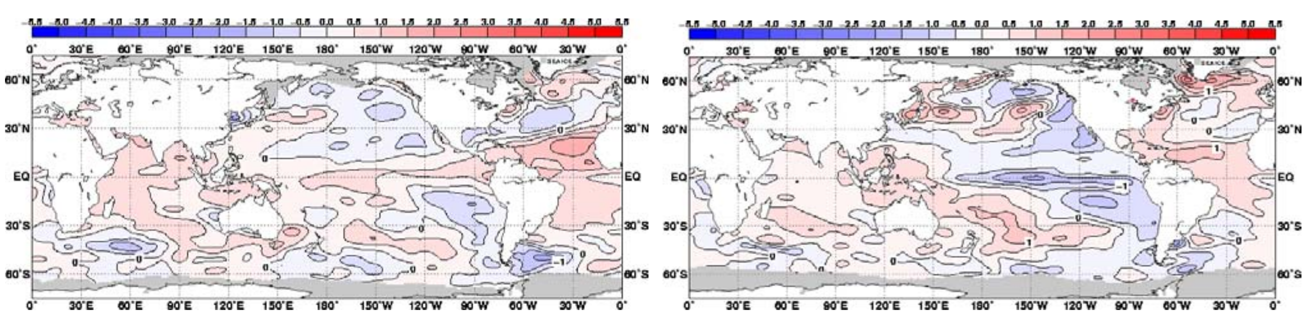

Fig. 4.2 Three-month mean sea surface temperature anomaly (unit: °C) for March – May (left) and June – August (right) 2010.

Atlantic, and were below normal over the central and eastern Pacific (Figure 4.2). Convective activity (inferred from OLR) associated with the Asian summer monsoon was suppressed across a broad area from northern India to the Indochina Peninsula and to the east of the Philippines in the first half of summer 2010, and was enhanced over the Arabian Sea and from the Indochina Peninsula to the north of the Philippines in the second half (Figure 4.3). Over the eastern Indian Ocean and on the Maritime Continent, convective activity was enhanced throughout the summer.

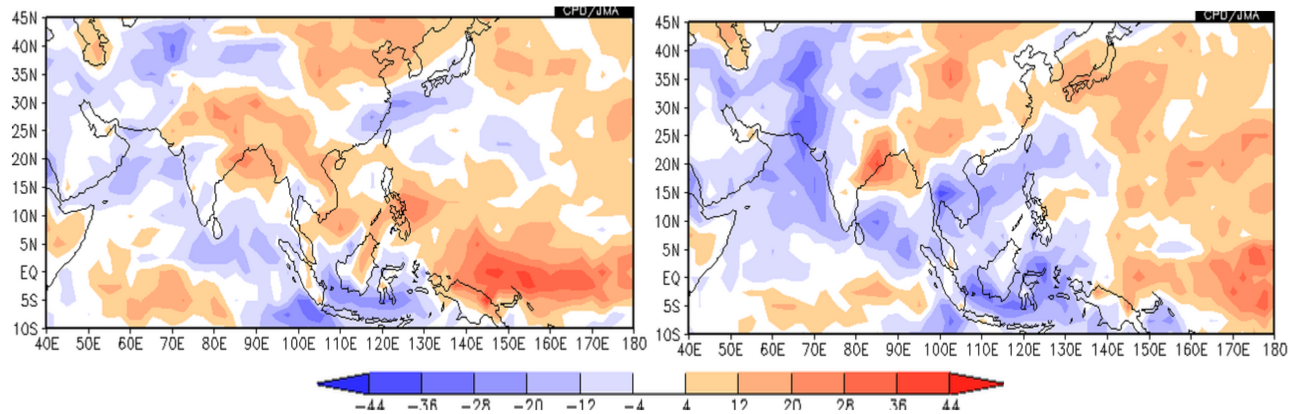

Fig. 4.3 Outgoing longwave radiation (OLR) anomaly (unit: W/m^2) in the first half (left) and the second half (right) of the summer 2010. Cold and warm shading indicates enhanced and suppressed convective activity, respectively, in relation to the normal.

5. Characteristic atmospheric circulation

5.1 Tropospheric air temperature

The zonally averaged tropospheric air temperature in the mid-latitudes of the Northern Hemisphere was the highest for summer (June – August) since 1979 (Figure 5.1). The zonally averaged tropospheric thickness in the tropics reached an above-normal level in July 2009 and matured in the first half of 2010 (Figure 5.2). In June 2010, the thickness in the tropics remained above normal but decreased, while that in the mid-latitudes of the Northern Hemisphere rapidly increased and remained significantly above normal throughout the summer. The evolution of a thickness anomaly similar to that seen in 2010 was identified in 1988 and 1998 (not shown). As research so far (*e.g.*, Angell 2000) has indicated, tropospheric air temperatures increase on a global scale after an El Niño event. Examination of past La Niña events shows a tendency for higher-than-normal tropospheric air temperatures in the mid-latitudes of the Northern Hemisphere. This is consistent with the results of previous research (*e.g.*, Seager *et al.* 2003). It is therefore possible that zonally averaged tropospheric air temperatures in the mid-latitudes of the Northern Hemisphere were extremely high in summer 2010 from the influence of the El Niño event and partly due to the effects of the La Niña event. A warming trend can be identified in the zonally averaged tropospheric air temperature in the mid-latitudes of the Northern Hemisphere (Figure 5.1). This trend may be associated with global warming due to the buildup of anthropogenic greenhouse gases.

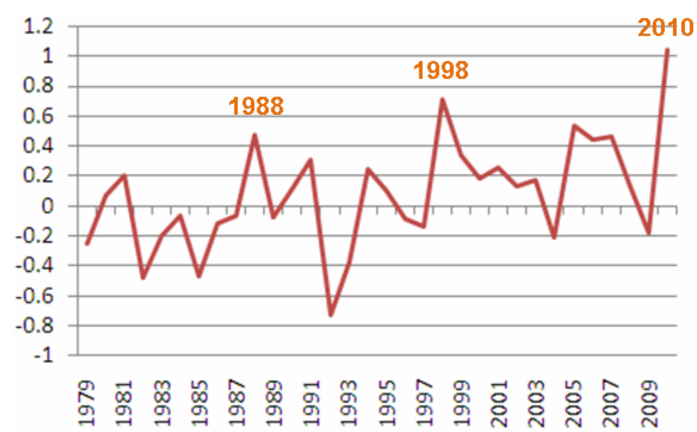

Fig. 5.1 Time series of three-month (June – August) zonally averaged temperature anomalies (unit: K) in the mid-latitudes (30°N – 60°N) of the Northern Hemisphere calculated from thickness (850 – 300 hPa).

5.2 Remarkably strong anticyclone over Japan

The subtropical jet stream in the vicinity of Japan showed a southward-shifted tendency from its normal position in the first half of summer 2010, while the jet stream was shifted northward of its normal position with a frequent northward meander (a ridge of high pressure) in the second half (Figure 5.3). In line with the characteristics of the subtropical jet stream, the extension of the Tibetan High to Japan was weaker than normal in the first half of summer 2010, while it was stronger than normal (Figure 5.4) and equivalent-barotropic highs developed and persisted over Japan in the second half (Figure 5.5). As detailed in Chapter 4, convective activity was broadly enhanced in and around the Indian Ocean in the second half of summer 2010 (Figure 4.3). Considering that research so far (*e.g.*, Krishnan and Sugi 2001; Enomoto 2004) indicates a link between the Asian summer monsoon and Japan's climate, statistical analysis was implemented to examine the relationship between convective activity linked to the Asian summer monsoon and the subtropical jet stream in the vicinity of Japan. The results indicated that when convective activity is enhanced (or suppressed) over the region from the northern Indian Ocean to the northeast of the Philippines (10°N – 20°N, 60°E – 140°E), the subtropical jet stream near Japan tends to shift northward (or southward) of its normal position (Figure 5.6). It therefore seems that the northward shift of the subtropical jet in the vicinity of Japan was associated with active convections across the broad region over and around the Indian Ocean. In addition, considering previous studies (*e.g.*, Nitta 1987) indicating the influence of convective activity around the Philippines on Japan, active convections from the northern South China Sea to the area northeast of the Philippines may have been partly responsible for the strength of anticyclones around Japan, especially from the second half of August to early September.

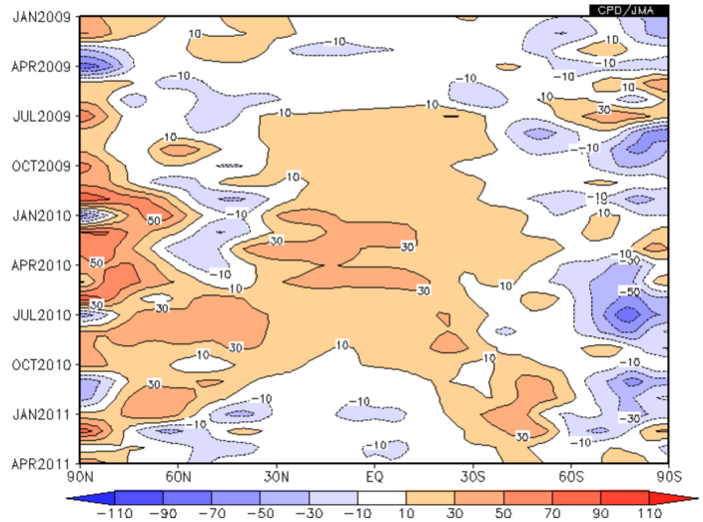

Fig. 5.2 Time-latitude cross section of monthly zonally averaged thickness (300 – 850 hPa) anomaly (unit: m) for January 2009 – March 2011.

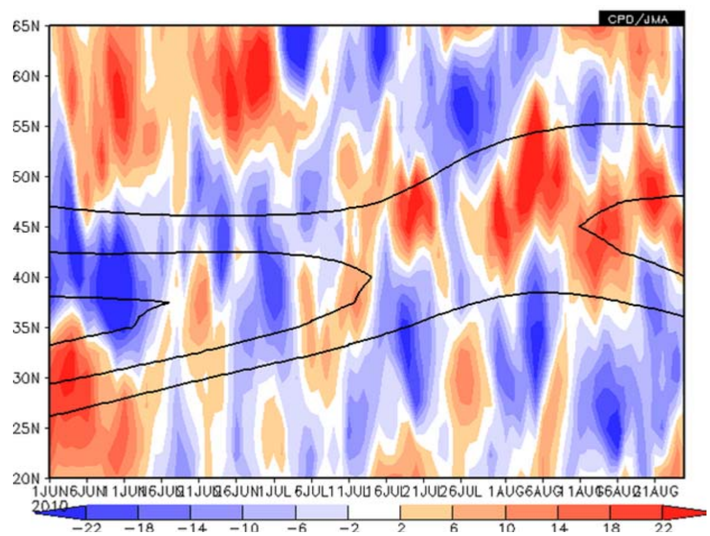

Fig. 5.3 Latitude-time cross section of normal (black lines) and anomalies (colored shading) of the 200-hPa zonal wind speed averaged in the vicinity of Japan (125˚E – 145˚E).

5.3 Okhotsk High

The Okhotsk High (a cool semi-stationary anticyclone) often develops around the Sea of Okhotsk from spring to autumn and occasionally brings cool air to the Pacific side of northern and eastern Japan, resulting in cool summers. In the period from June to the first half of July 2010, the Okhotsk High was less developed than in past years (Figure 5.7). In addition, warm anticyclones frequently covered Japan (particularly its northern parts), and significant anticyclones to the east of the country brought warm air from the south, leading to significantly higher-than-normal temperatures in the first half of summer 2010 (Figure 5.8). A blocking high in the upper troposphere over the Sea of Okhotsk plays an integral role in the formation of the Okhotsk High (Nakamura and Fukamachi 2004). In the first half of July, a blocking high developed near the Sea of Okhotsk, but its position was not suitable for the formation of the Okhotsk High. In the second half of

July, the phenomenon temporarily appeared but influenced Japan little due to the northward shift of the subtropical jet near the country and the strong Pacific High to its east.

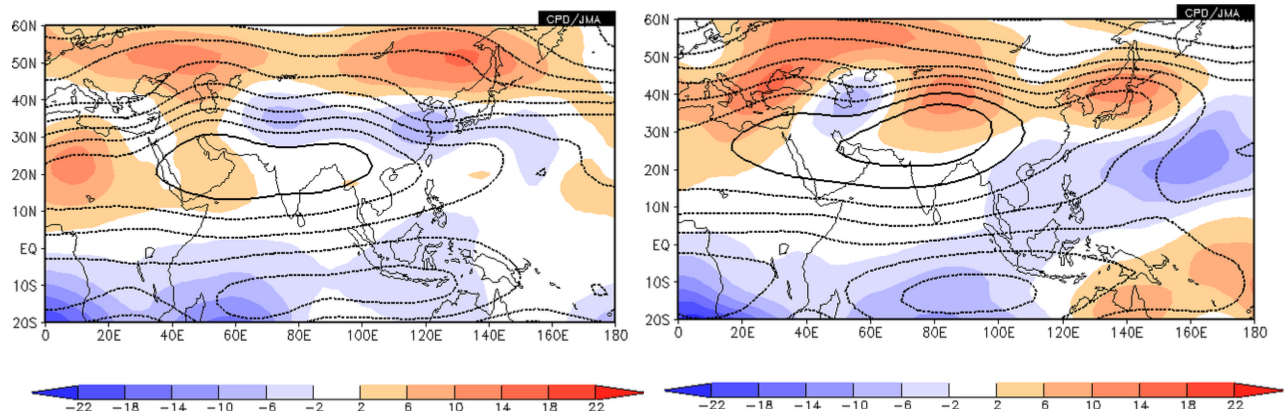

Fig. 5.4 Monthly-mean 200-hPa stream function and anomaly for June (left) and August (right) 2010. The contours show the stream function at intervals of 1×10^7 m^2/s, and the shading indicates stream function anomalies. In the Northern (Southern) Hemisphere, warm (cold) shading denotes anticyclonic (cyclonic) circulation anomalies.

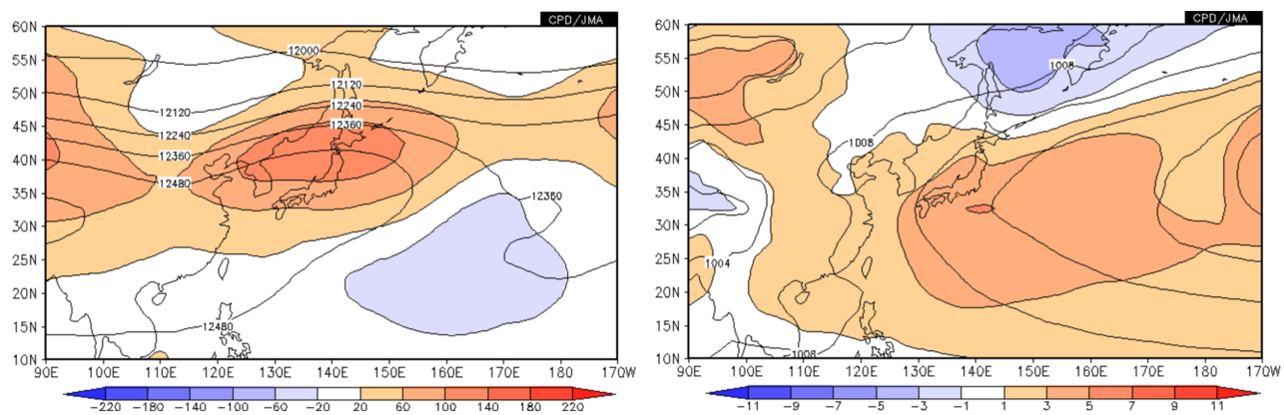

Fig. 5.5 Monthly-mean atmospheric circulation around Japan for August 2010. Left panel: The contours indicate 200-hPa height at intervals of 120 m. Right panel: The contours indicate sea level pressure at intervals of 4 hPa. The shading shows their anomalies.

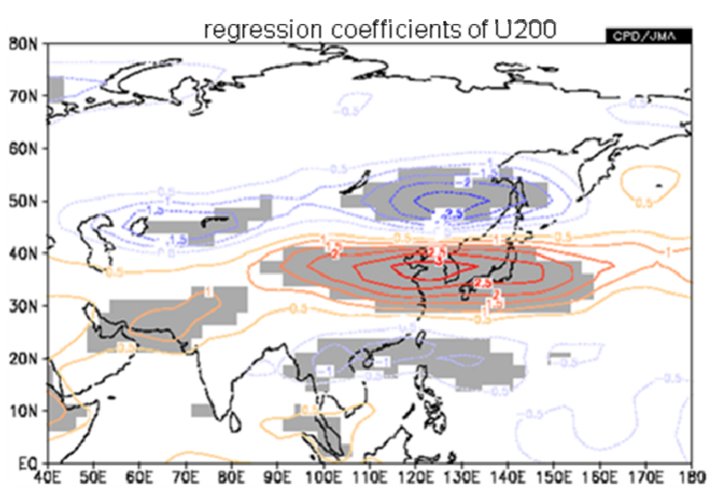

Fig. 5.6 Linear regression coefficients of 200-hPa zonal wind speed onto area-averaged convective activity (OLR) over the region from the northern Indian Ocean to the area northeast of the Philippines (10°N – 20°N, 60°E –140°E) for July and August. When convective activity was enhanced (suppressed) over the region, the subtropical jet stream to the north of Japan was stronger (weaker) than normal at the cold (warm) colored contours. The shading shows a 95% confidence level based on F-testing. The base period for the statistical analysis is 1979 – 2009.

6. Conclusion

The Advisory Panel on Extreme Climate Events summarized the characteristics of the atmospheric circulations leading to the extremely hot summer in Japan and identified the major factors contributing to them as follows:

(1) The zonally averaged tropospheric air temperature in the mid-latitudes of the Northern Hemisphere reached its highest summer level since 1979. This can be attributed to the delayed effect of the El Niño event and partly to the effects of the La Niña event.

(2) Japan was significantly influenced by the pronounced Pacific High caused by enhanced convection in the broad area over the Indian Ocean and the surrounding seas. It is possible that the broadly active convection was associated with above-normal SSTs over the Indian Ocean and with the La Niña event.

(3) Japan was influenced less than usual by the Okhotsk High (a cool semi-stationary anticyclone) because the occurrence frequency of the Okhotsk High itself was lower than normal. In addition, a predominant anticyclone to the east of Japan intercepted the influence of the Okhotsk High.

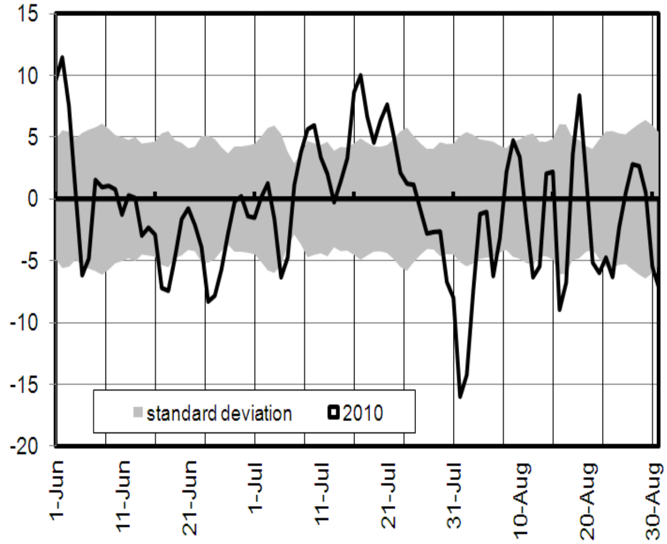

Fig. 5.7 Time series of average sea level pressure anomaly (unit: hPa) over the Sea of Okhotsk (45°N – 60°N, 140°E – 155°E) from June to August 2010. The thick line indicates daily mean values of the area-averaged sea level pressure anomaly over the region. The gray shading denotes the range of one standard deviation.

These atmospheric characteristics and the factors that may have contributed to them are illustrated in Figure 6.1 The primary factors outlined above are supported by statistical analysis and research performed to date, but the results of this work do not wholly explain the extreme conditions seen. In order to further understand the event and clarify the dynamic mechanism behind it, it is necessary to investigate other possible

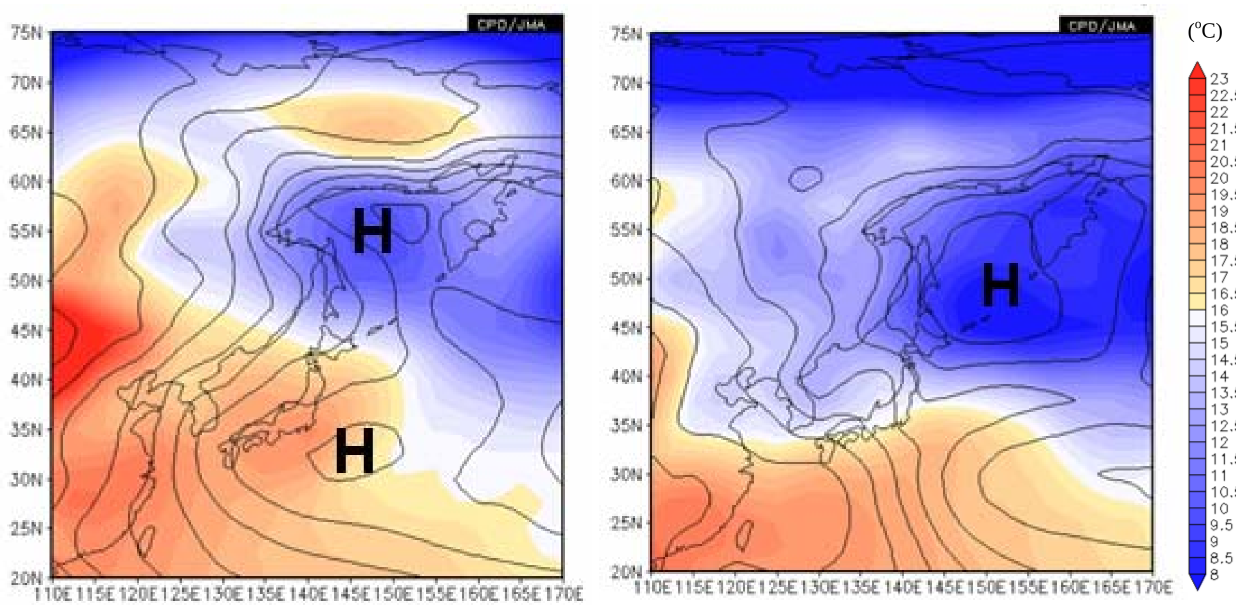

Fig. 5.8 The cool semi-stationary anti-cyclone (Okhotsk high). The contours show sea level pressure, and the shading indicates temperature at 850 hPa. The left panel and right panel are for 15 -24 July 2010 and for 19 - 28 July 2093, respectively.

factors and perform numerical model experiments.

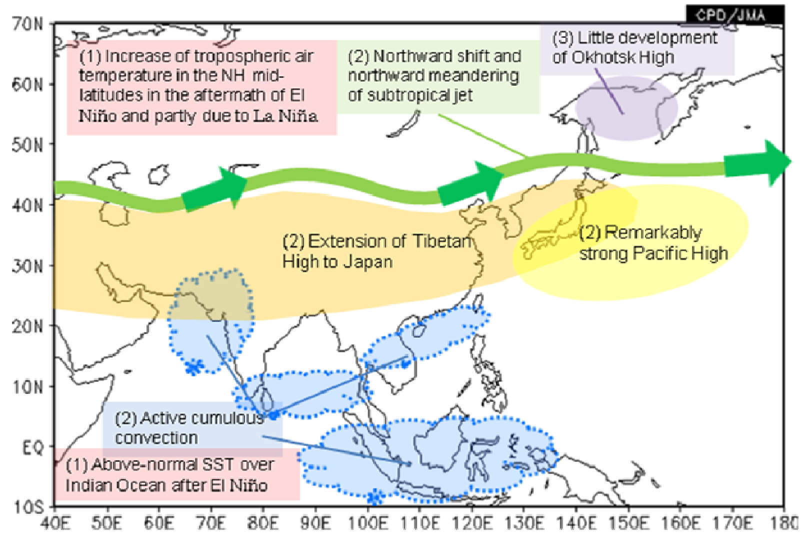

Fig. 6.1 Primary factors contributing to Japan's extremely hot summer (June – August) of 2010. Here, (1), (2) and (3) correspond to the numbers in Chapter 6 of the main text.

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