Quasi-biweekly intensification of Pacific-Japan pattern that caused an intense heat over Japan in late July 2023

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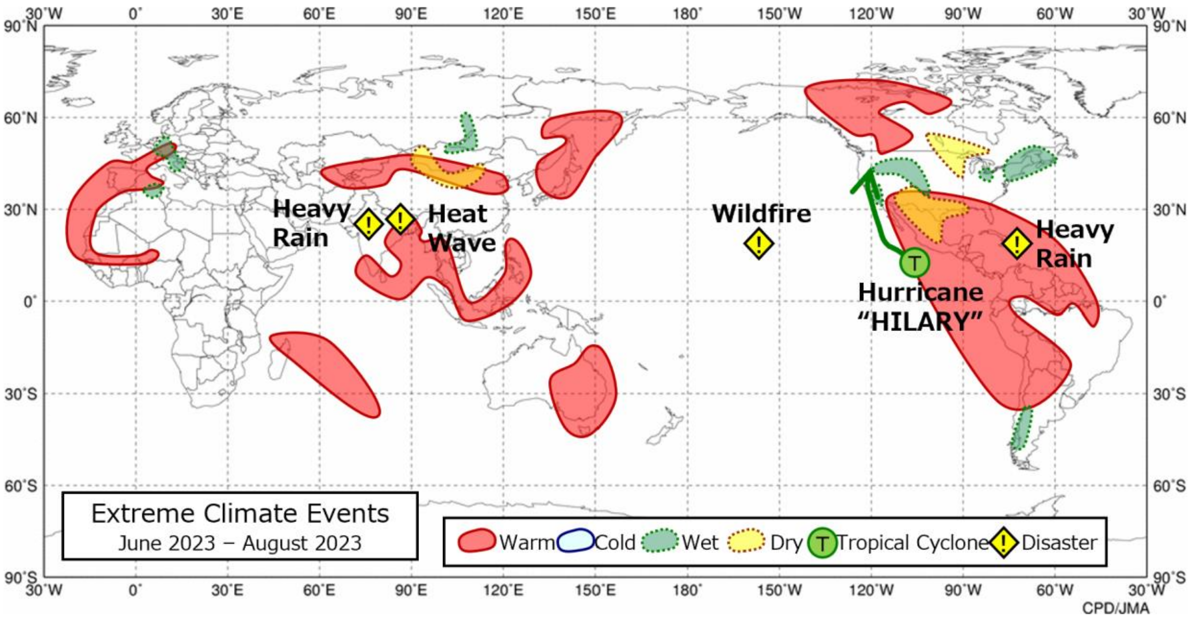
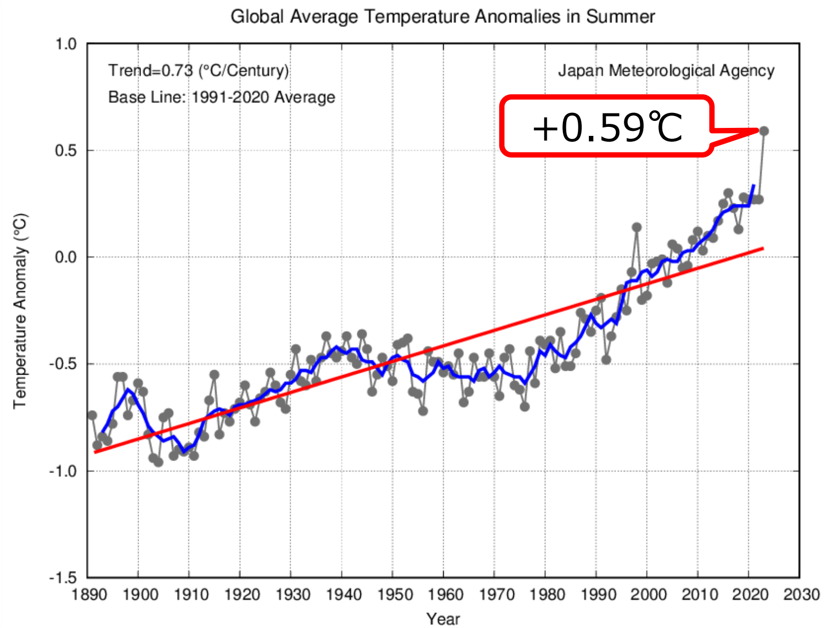
Outline

I. Introduction
II. Data and Analysis Methods
III. Results
IV. Summary

Global Climate in Summer 2023



Extreme climate events and weather-related disasters during summer 2023



Seasonal anomalies of global average surface temperature in summer

- ◆ Surface temperatures over the world in summer 2023 have reached the highest levels in the recorded history since 1891.
- ◆ The long-term rising temperature is likely to act as a background in tendencies of global-scale above-normal temperatures.

Climate in Japan in Summer 2023

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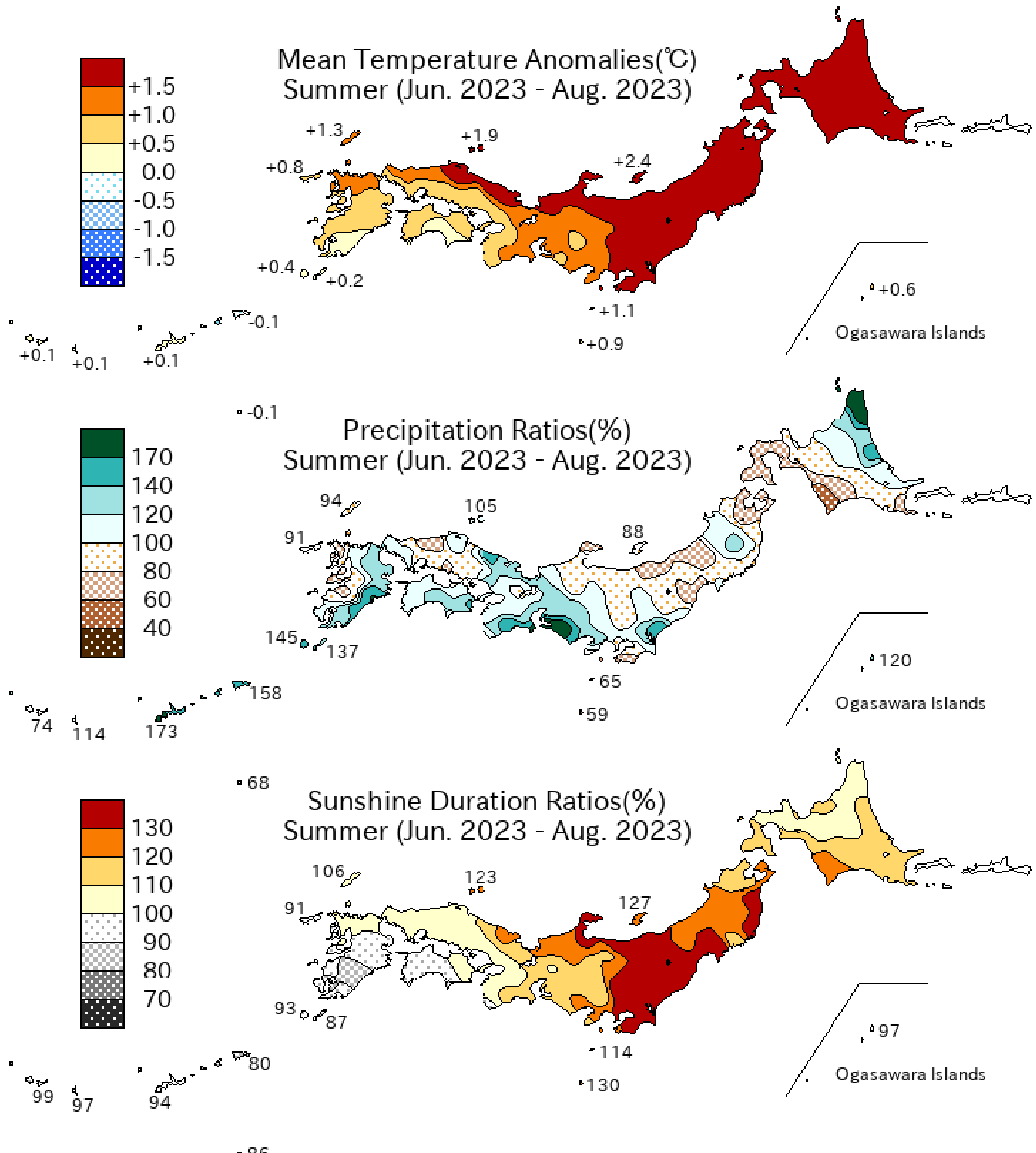
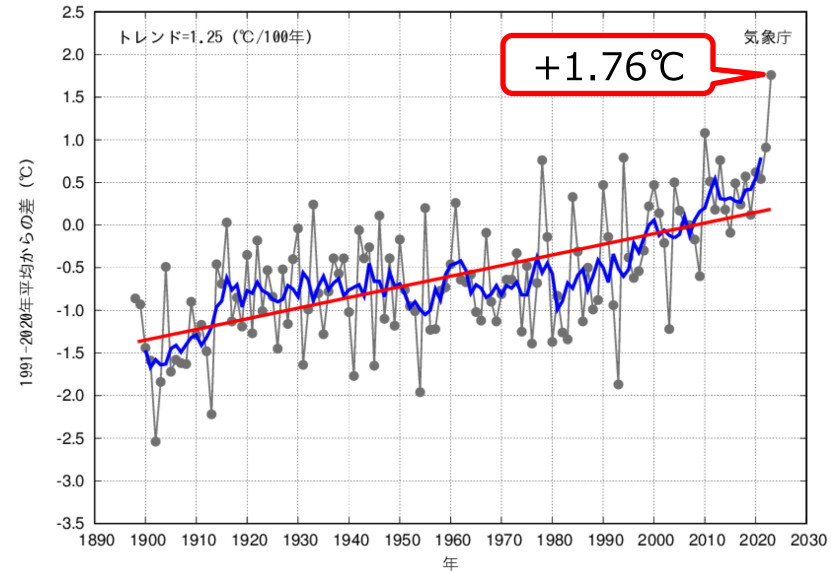


Seasonal anomalies of global average surface temperature in summer



- Summer mean temperatures were the highest in summer from 1946, and sunshine durations were significantly above normal in northern/eastern Japan.
- Surface temperatures in Japan have reached the highest levels in the recorded history since 1898.

Intense Heat from Late July 2023 onward

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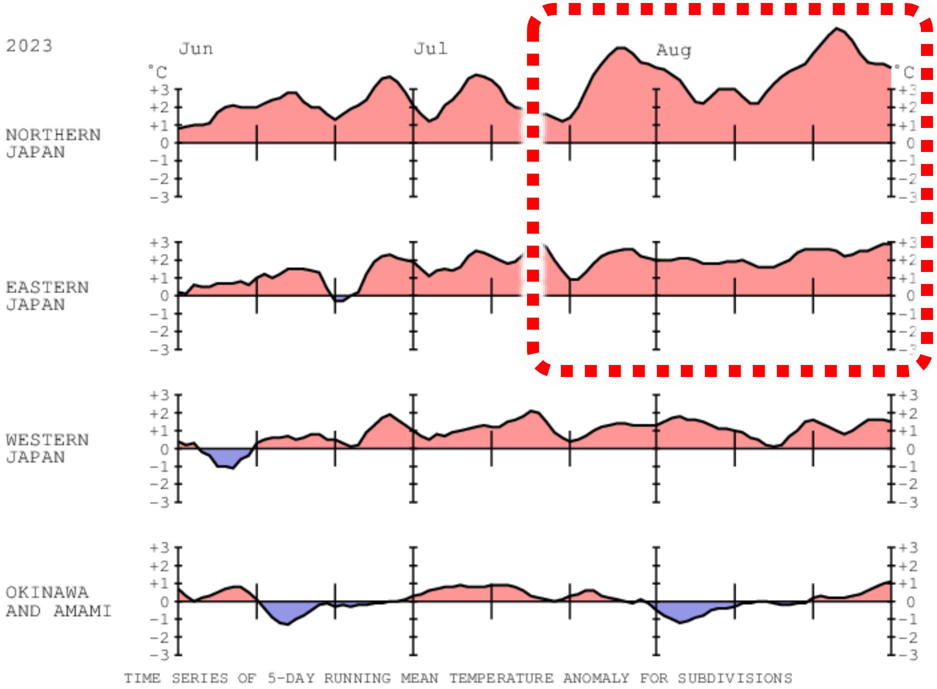
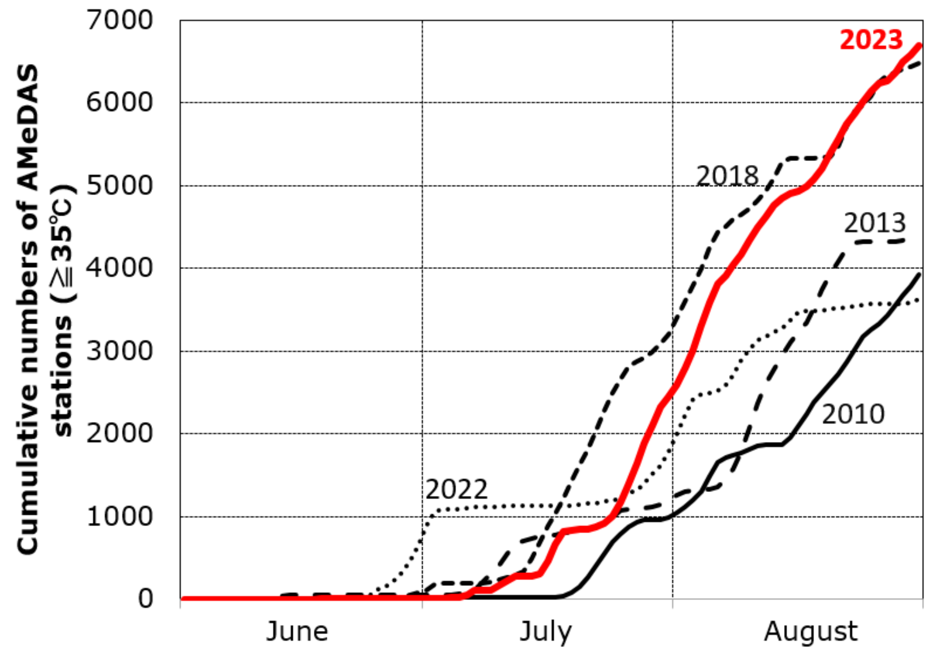


Time series of 5-day running mean temperature anomalies (°C) in summer 2023 over four subdivisions in Japan



Time series of cumulative numbers of AMeDAS stations with daily maximum temperatures of 35°C or higher for 2023

Black lines: 2010, 2013, 2018 and 2022

- Especially northern and eastern Japan experienced significantly high temperatures from late July to August, accompanied by increased number of significantly hot (T_{max}≧35°C) days and many fatalities due to heat stroke.
- Triggering primary factors of the intense heat in late July diagnosed by the JMA's advisory panel on extreme climate events are briefly presented here.

Data and Analysis Methods

☐ Dataset

- ✓ In-situ observational station data of surface temperature over Japan were obtained from the JMA Automated Meteorological Data Acquisition System (AMeDAS)
- ✓ JRA-3Q (the Japanese Reanalysis for Three Quarters of a Century; Kosaka et al. 2024) since 1948 with horizontal resolution of 1.25°
- ✓ MGDSST (Merged Satellite and In-situ Data Global Daily Sea Surface Temperature; Kurihara et al. 2006)
- ✓ OLR (Outgoing Longwave Radiation) provided by NOAA (Liebmann and Smith 1996)

☐ Analysis Methods

- ✓ Normal was defined as average for the period from 1991 to 2020, and anomalies as deviations from the normal.
- ✓ To diagnose an effect of rich moisture on the anomalous circulation, vertically integrated APE generation due to anomalous diabatic heating (CQ) was derived as follows (Kosaka et al. 2010).

$$\mathrm{CQ} = \frac{R^2}{Sp^2}\frac{T'Q'}{C_p}$$

R: gas constant, *S*: static stability, *p*: pressure, *T*: temperature
Q: convective heating rate, C_p: constant pressure specific heat
': anomaly

SST anomalies in July

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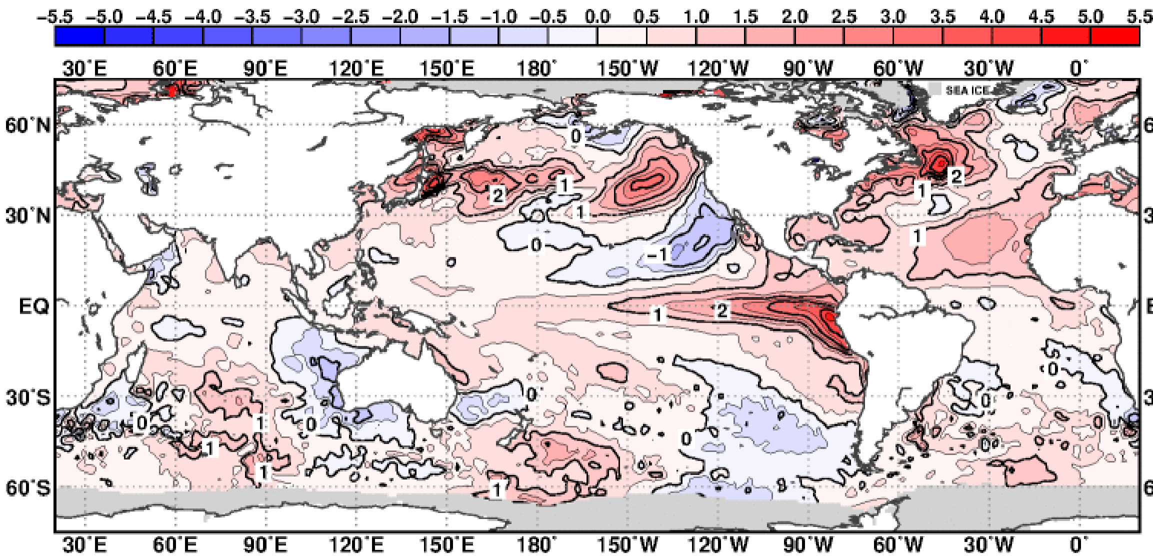
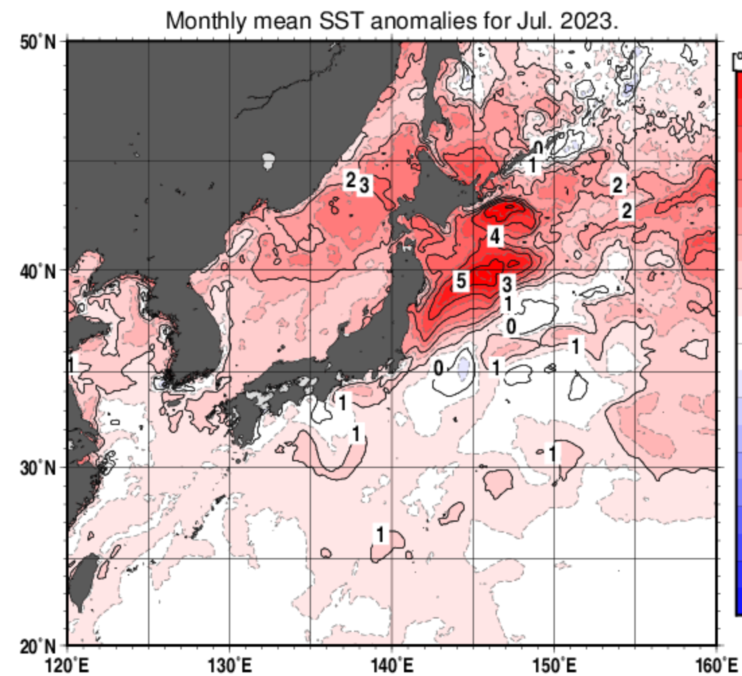


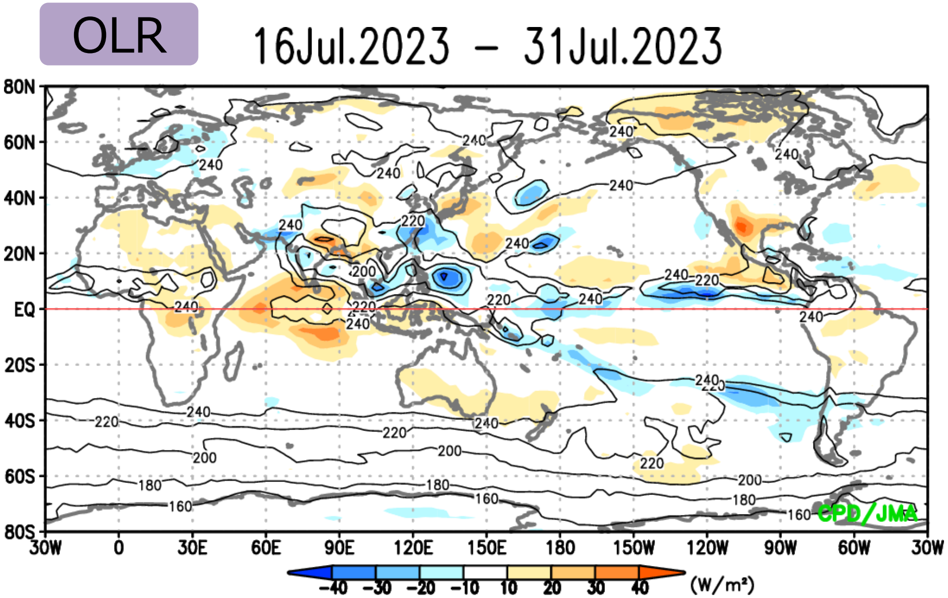
Monthly mean sea surface temperature anomalies based on COBE-SST2 and MGDSST* (Jul. 2023)



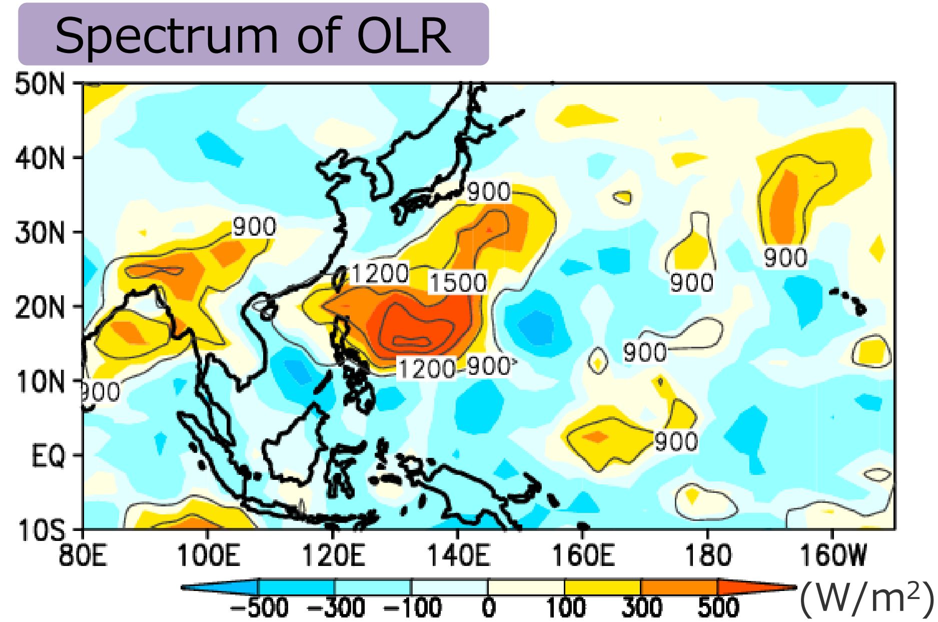
SST anomalies averaged in July 2023 over the global area and near Japan

- SSTs showed significantly positive SST anomalies not only in the central to eastern equatorial Pacific in association with a developing El Niño, but also in the western equatorial Pacific with the warm water.
- A zonal contrast of SST anomalies in the equatorial Indian Ocean indicates a developing phase of the positive IOD.
- SSTs around Japan was significantly above-normal particularly over the Sea of Japan and over the seas in the Kuroshio Extension, possibly affecting above-normal surface temperatures in Japan.

Tropical Convection in Late July



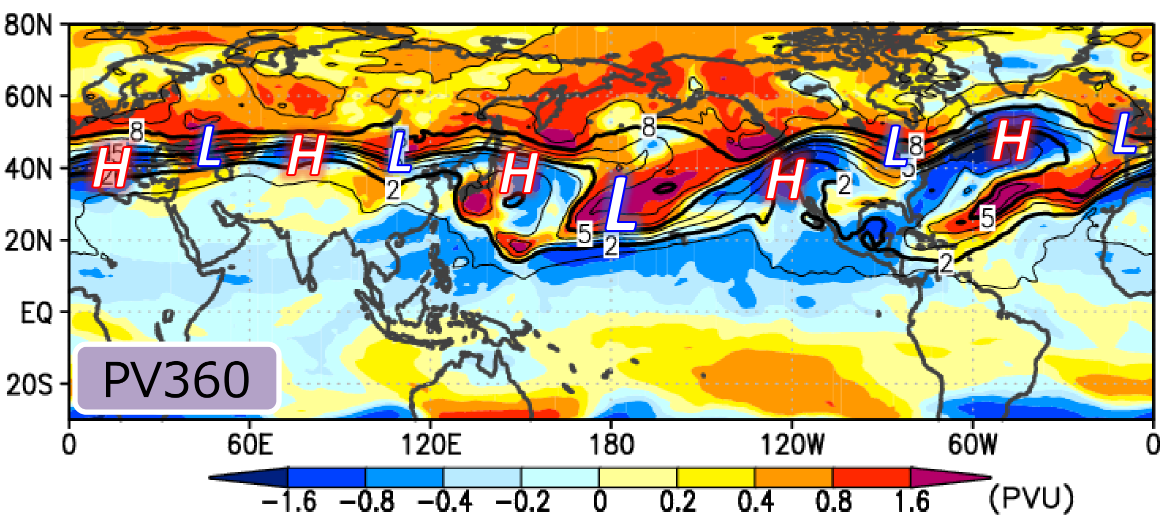
OLR (contours) and the anomalies (shading) averaged in 16–31 July 2023

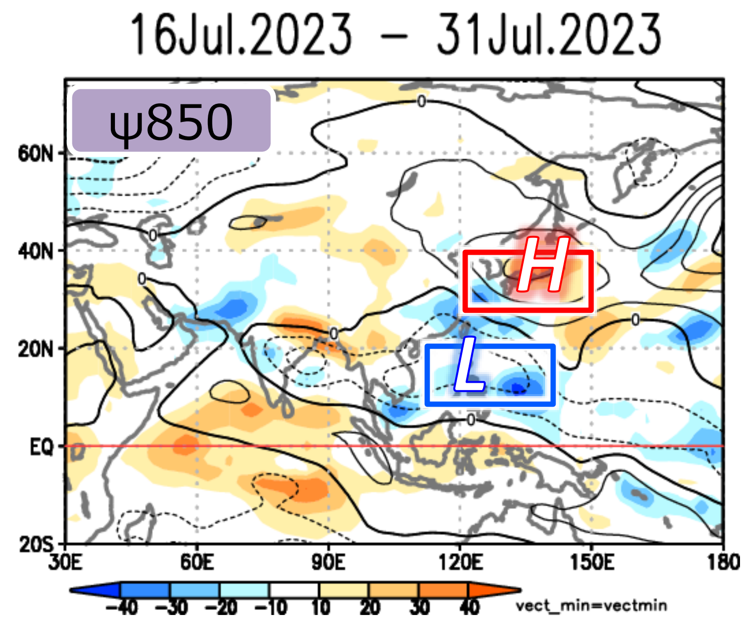


Power spectrum of OLR with a period of 10–20 days during the period of MJJAS 2023 (contours) and the anomalies (shading)

- ◆ Tropical convection was intensified over the equatorial Pacific in association with positive SST anomalies.
- ◆ Active convection including a series of typhoon formation significantly migrated northwestward from the equatorial western Pacific to the seas near the Philippines with a typical period of bi-week (10–20 days), promoting the enhanced convection near the Philippines in late July.

Upper- and Lower-level Circulation in Late July





(Upper panel) Potential vorticity at 360K (contours) and the anomalies (shading) and (Right panel) 850hPa stream function anomalies (contours) in 16–31 July 2023

- ◆ The upper-level hemispheric-scale Rossby wave train was dominant, causing the poleward-displaced subtropical jet over Japan. The wave train can originate the intensified mid-Pacific trough (MPT). The low- and high- PV air masses detached from the markedly deformed Tibetan high and the intensified MPT toward east and south of Japan, respectively, contributing to the enhanced convection near the Philippines.
- ◆ The lower-level North Pacific Subtropical High (NPSH) was markedly intensified in association with the enhanced convection, corresponding to the Pacific–Japan (PJ) pattern (Nitta 1987).

Record intensification of PJ Pattern in the end of July

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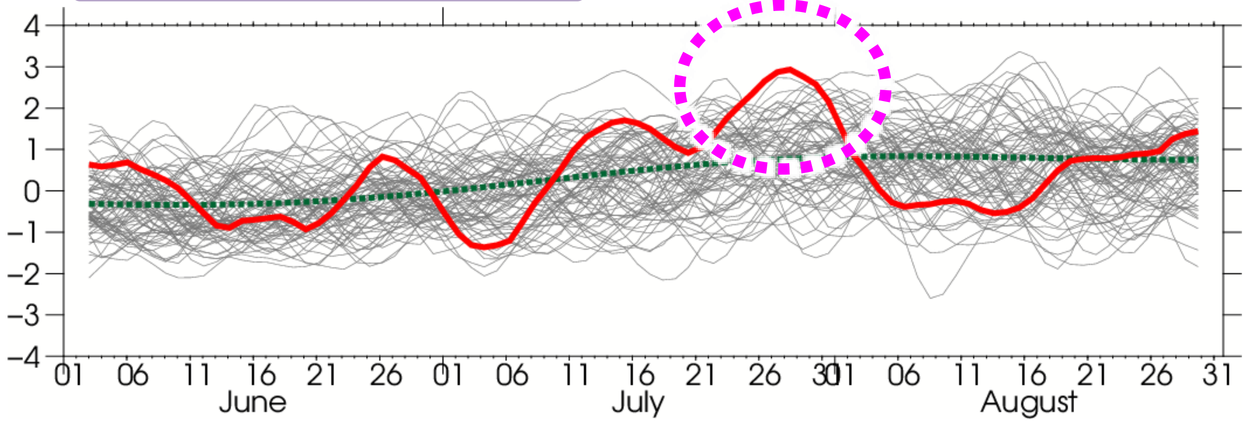
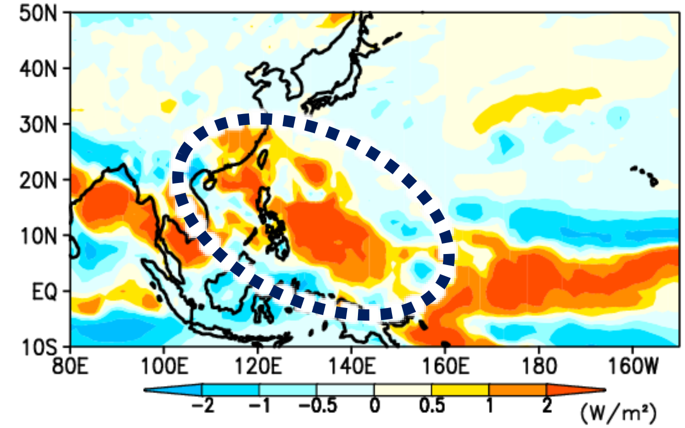
Index of PJ pattern



Five-day running-mean time series for the index of PJ pattern, defined by a difference between 850-hPa relative vorticity averaged near the Philippines (blue box in the previous slide) and that averaged near Japan (red box).

Red: 2023, Green: Normal, Gray: 1948–2022

CQ



Vertically integrated (from 975 to 100hPa) CQ in 16–31 July 2023

- The PJ pattern accompanied by cyclonic circulation near the Philippines and the intensified NPSH was significantly intensified to an unprecedented degree in the end of July.
- Diabatic heating rate in the troposphere was significantly high near the Philippines due to anomalously rich moisture despite a developing phase of El Niño, contributing to effective APE generation that markedly intensified the PJ pattern.

Impact on Climate in Japan in late July

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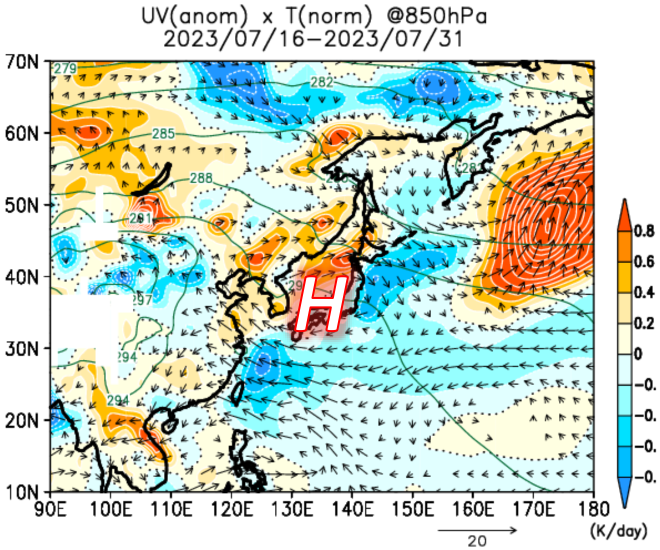
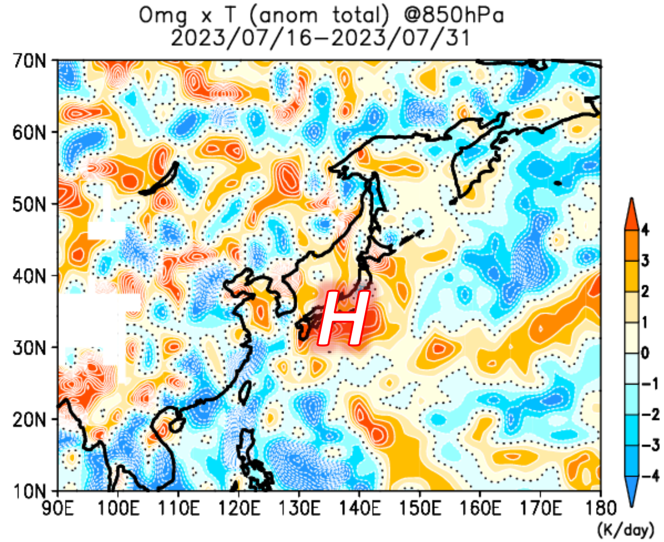
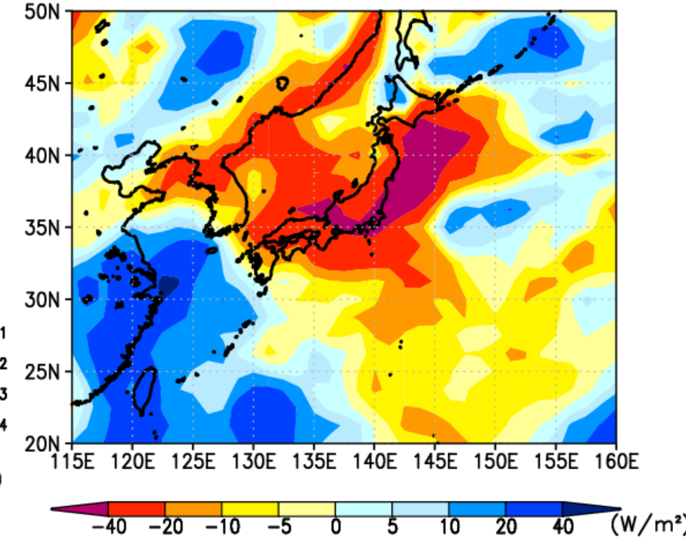
Horizontal Temperature Advection



Adiabatic Heating



Shortwave Radiation



Tendencies of temperature anomalies (unit: K d^{-1}) due to advection of normal temperature by (left panel) horizontal and (middle panel) vertical wind anomalies, and (right panel) shortwave radiation flux anomalies (unit: W m^{-2}) averaged in 16–31 July 2023

- Intensified warm air advection toward northern Japan with the periphery of NPSH, adiabatic heating due to anomalous descent and the downward short wave radiation anomalies near the NPSH contributed to significantly above-normal surface temperatures in Japan.

Summarization for Factors of Intense Heat

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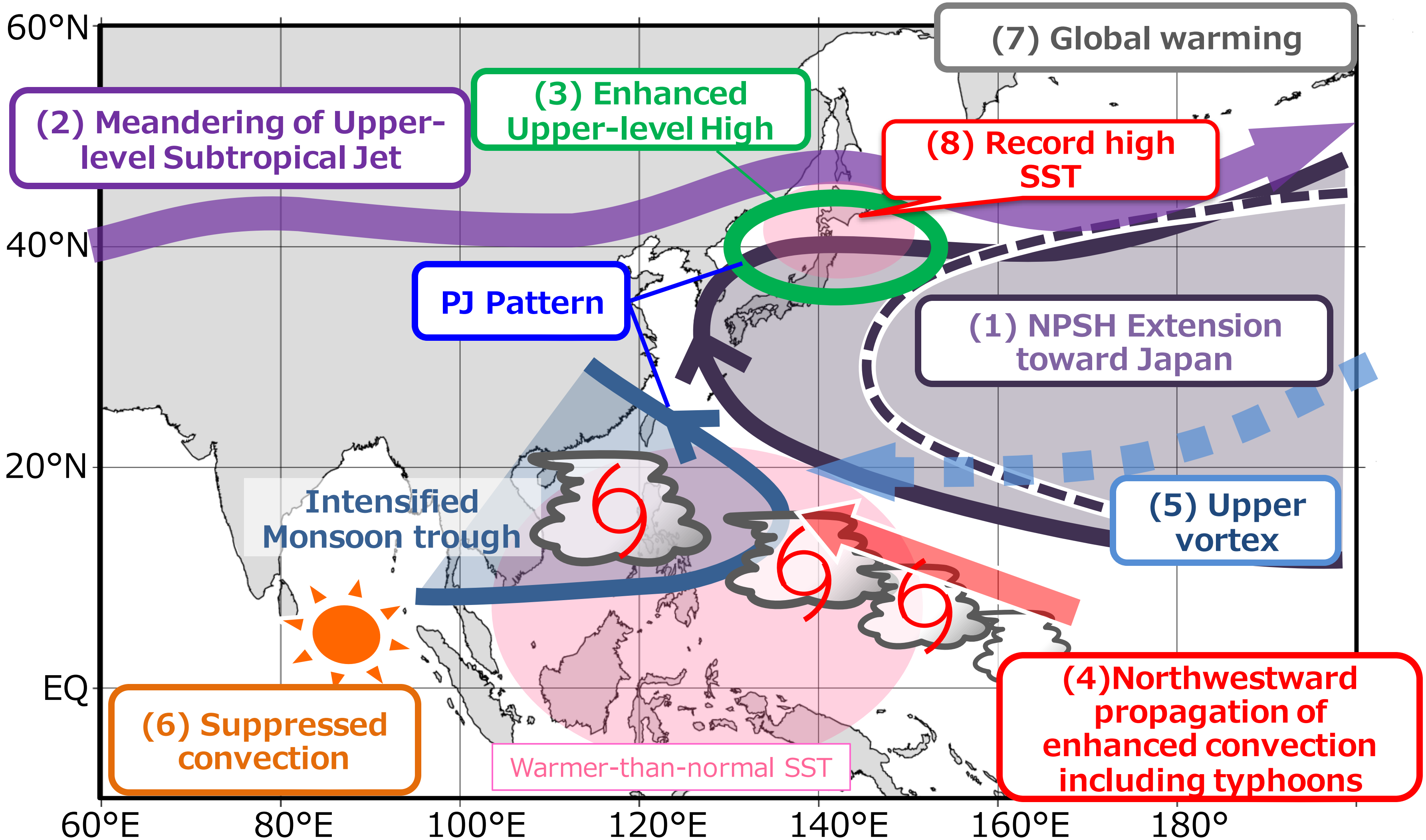


Schematics for the unprecedented heatwave in the late July 2023.

References

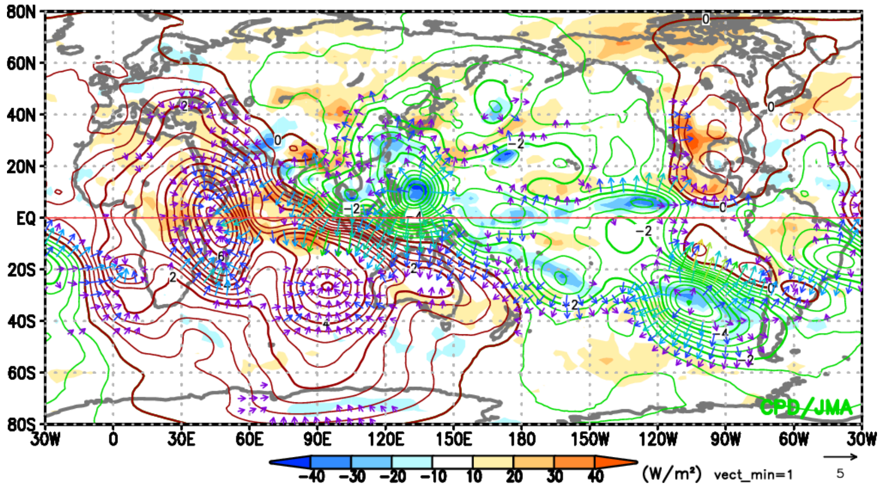
- ✓ Kosaka Y., S. Kobayashi, Y. Harada, C. Kobayashi, H. Naoe, K. Yoshimoto, M. Harada, N. Goto, J. Chiba, K. Miyaoka, R. Sekiguchi, M. Deushi, H. Kamahori, T. Nakaegawa; T. Y. Tanaka, T. Tokuhiro, Y. Sato, Y. Matsushita, K. Onogi, 2024: The JRA-3Q Reanalysis. *J. Meteor. Soc. Japan*, **102**, accepted.
- ✓ Kosaka, Y., and H. Nakamura, 2010: Mechanisms of meridional teleconnection observed between a summer monsoon system and a subtropical anticyclone. Part I: The Pacific–Japan pattern. *J. Climate*, **23**, 5085–5108.
- ✓ Kurihara, Y., T. Sakurai, and T. Kuragano, 2006: Global daily sea surface temperature analysis using data from satellite microwave radiometer, satellite infrared radiometer and in-situ observations. *Weather Service Bulletin*, **73**, Special issue, s1-s18 (in Japanese).
- ✓ Liebmann, B. and C. A. Smith, 1996: Description of a complete (interpolated) outgoing longwave radiation dataset. *Bull. Amer. Meteor. Soc.*, **77**, 1275–1277.
- ✓ Nitta, T., 1987: Convective activities in the tropical western Pacific and their impact on the Northern Hemisphere summer circulation. *J. Meteor. Soc. Japan*, **65**, 373-390.

SUPPLEMENTAL MATERIALS

Other maps averaged in 16–31 July

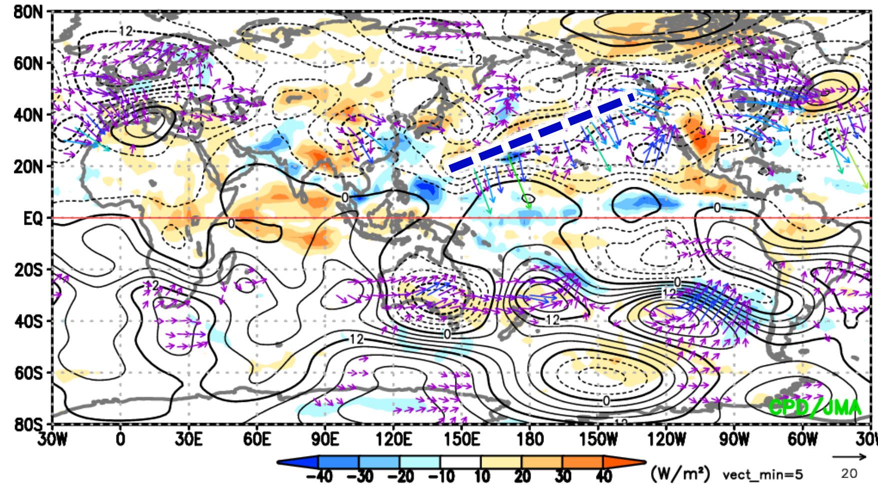
χ200

16Jul.2023 – 31Jul.2023



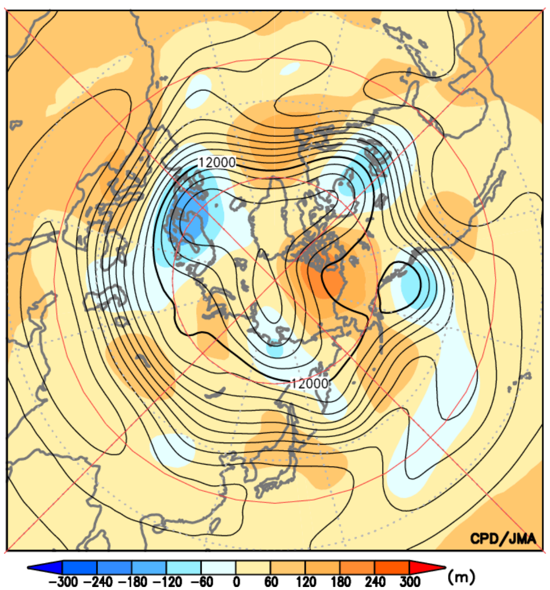
ψ200

16Jul.2023 – 31Jul.2023



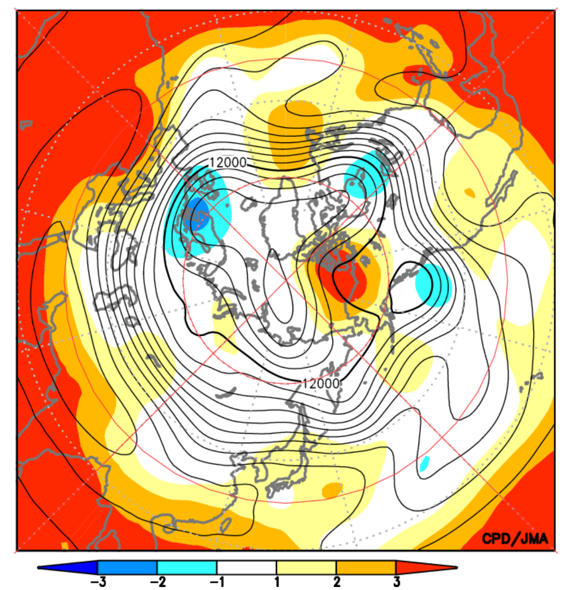
Z200

16Jul.2023 – 31Jul.2023



Normalized Z200 anom.

16Jul.2023 – 31Jul.2023



Upper-level High-PV Advection

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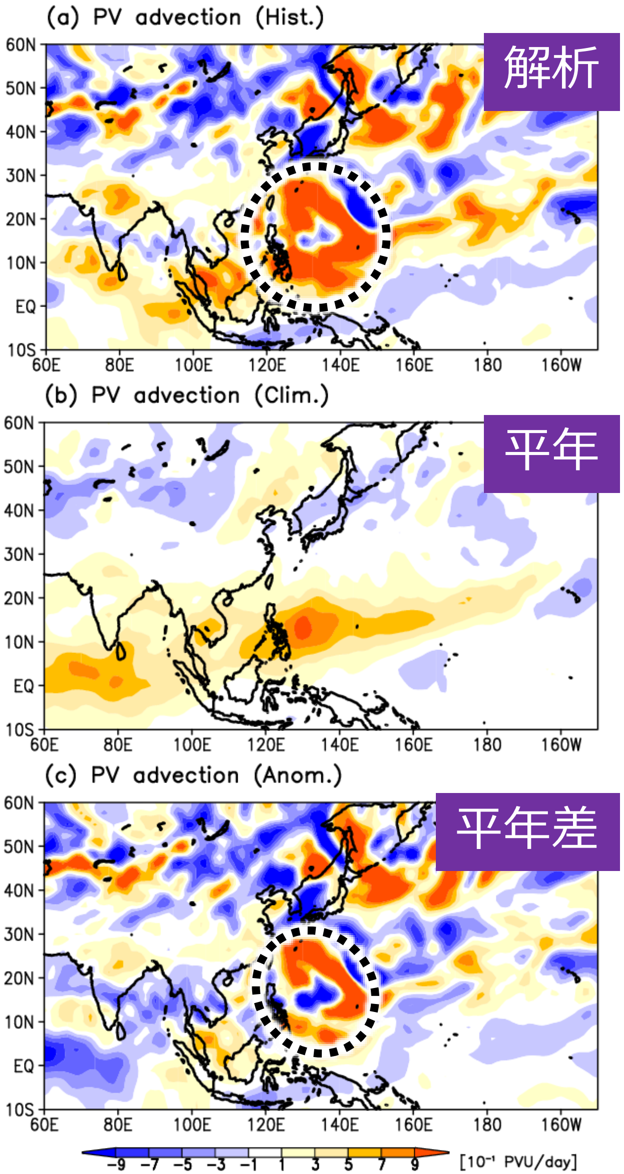
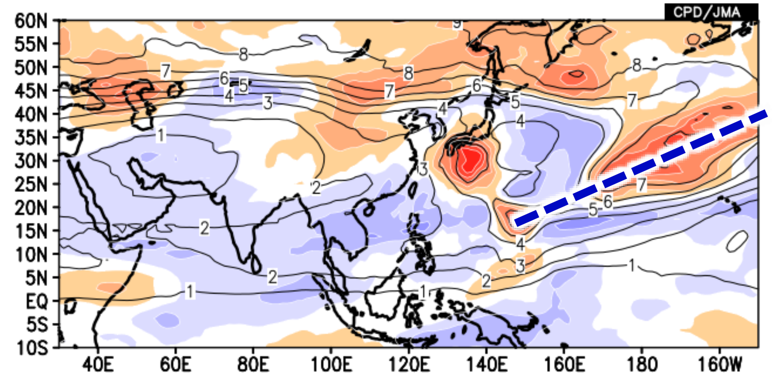
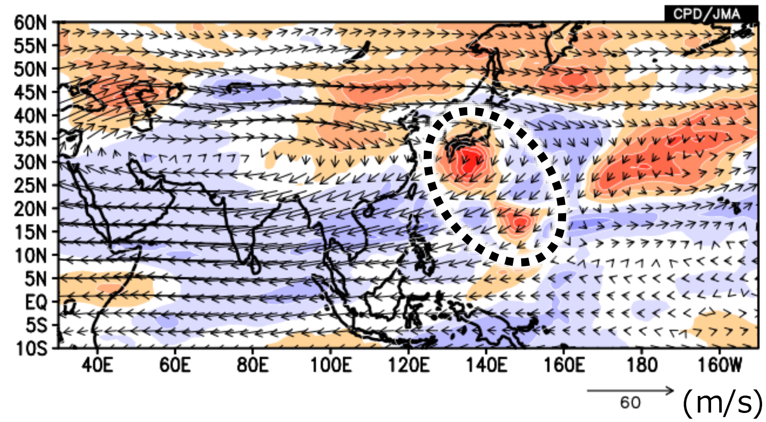
370K PV advection

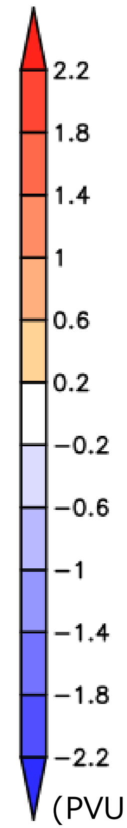


370K PV (Contour) & anom. (Shading)



370K PV anom. (Shading) & wind (vectors)





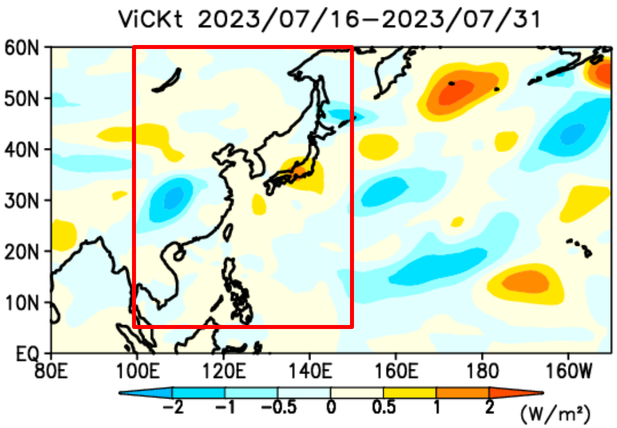
- ◆ High-PV anomalies south of Japan and climatological southerlies with the eastern periphery of Tibetan high promoted strong positive PV advection, partly contributing to enhanced convection near the Philippines.

Energetics of intensified PJ pattern in late July

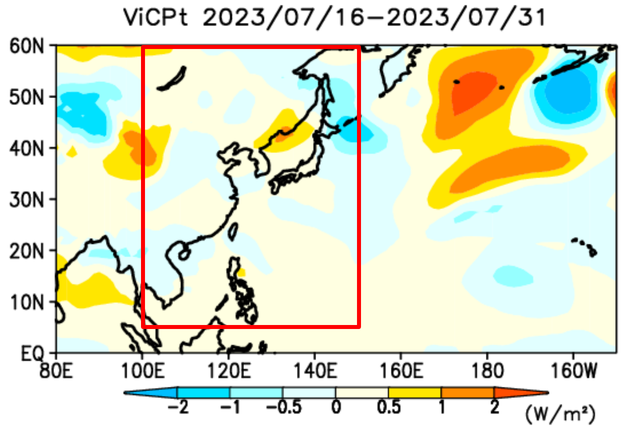
Energy Conversion (7/16～31)

※vertically integrated from surface to 100hPa

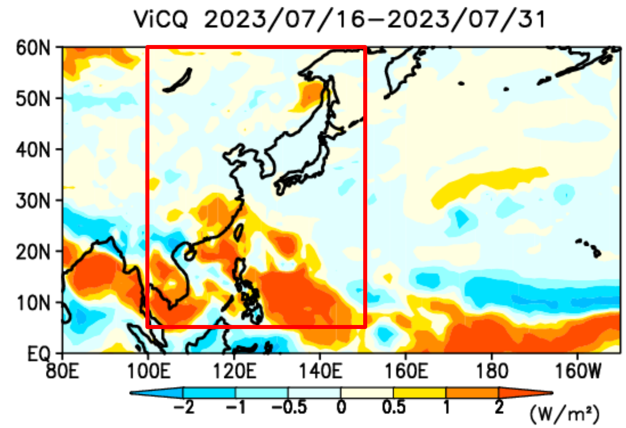
Barotropic Conversion (CK)



Baroclinic Conversion (CP)



APE generation by diabatic heating (CQ)



Conversion Efficiency

$\tau_{CK} = \langle KE \rangle_{NH} / \langle CK \rangle_{WP}$,

$\tau_{CP} = \langle APE \rangle_{NH} / \langle CP \rangle_{WP}$,

$\tau_{CQ} = \langle APE \rangle_{NH} / \langle CQ \rangle_{WP}$,

$\tau_{dry} = \langle KE + APE \rangle_{NH} / \langle CK + CP \rangle_{WP}$,

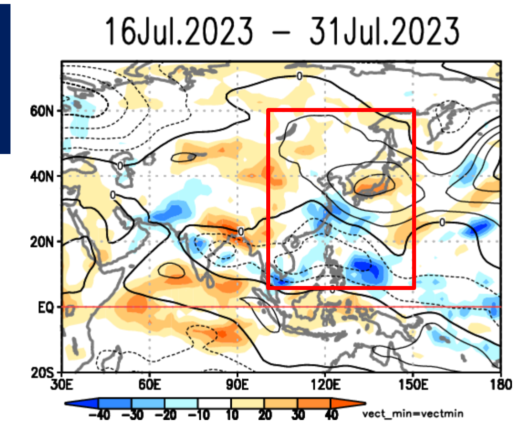
$\tau_{moist} = \langle KE + APE \rangle_{NH} / \langle CQ \rangle_{WP}$,

NH: 5-85N

WP: 5-60N, 100-150E

τ_{CK}	-69.5 day
τ_{CP}	22.6 day
τ_{CQ}	2.9 day
τ_{dry}	52.8 day
τ_{moist}	5.1 day

Ψ850 anom. (7/16～31)



◆ CQ primarily contributed to energetics of the intensified PJ pattern, indicating an important role of anomalously rich moisture east of the Philippines.

Northwestward-Migrating Enhanced Convection

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1-5 Jul.

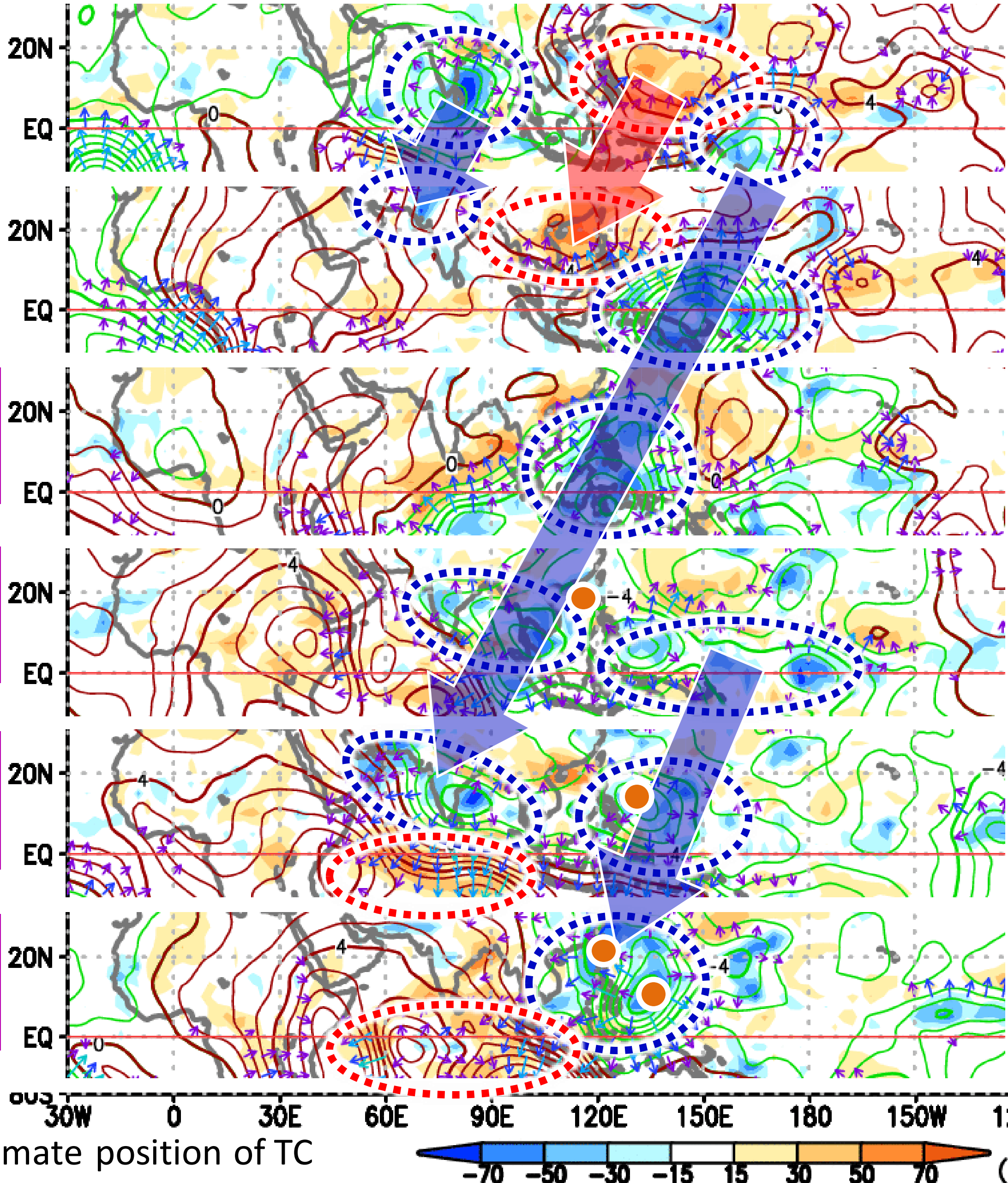
6-10 Jul.

11-15 Jul.

16-20 Jul.

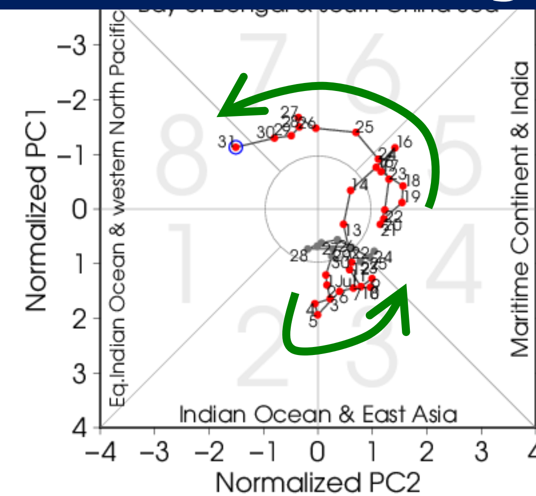
21-25 Jul.

26-30 Jul.



● : Approximate position of TC

BSISO-I Phase Diagram



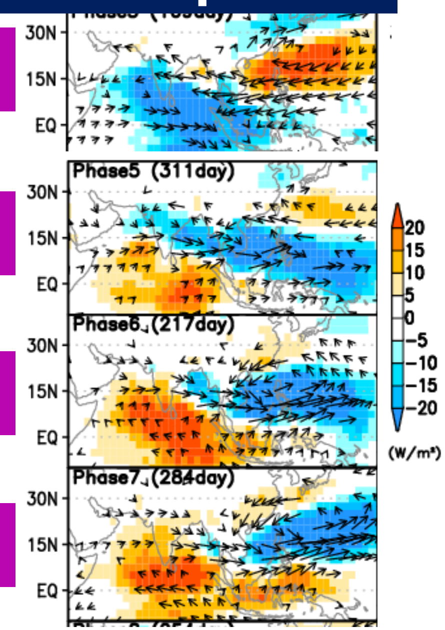
BSISO-I Composite

P3

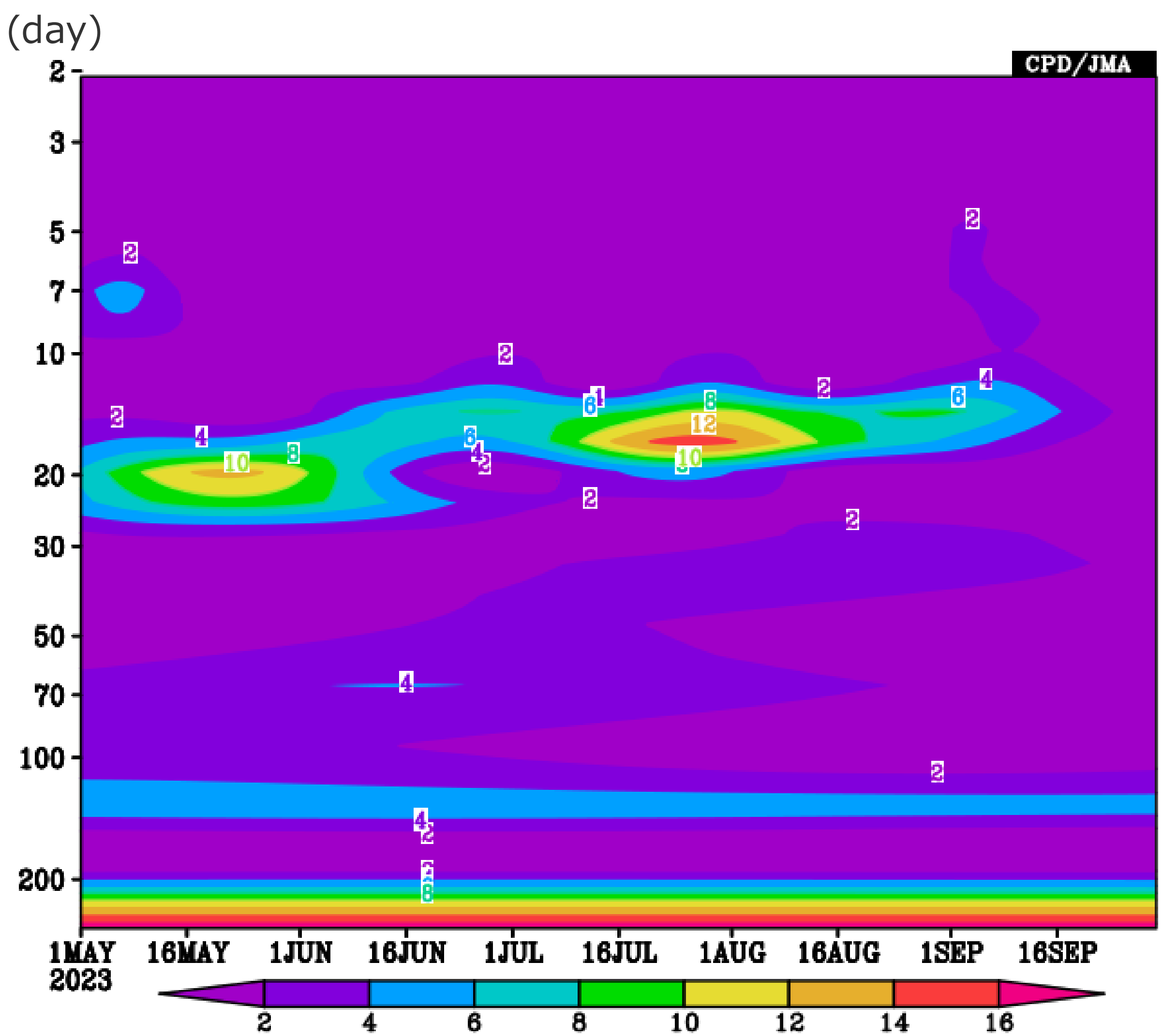
P5

P6

P7



Wavelet Analysis of OLR anomalies in MJJAS 2023

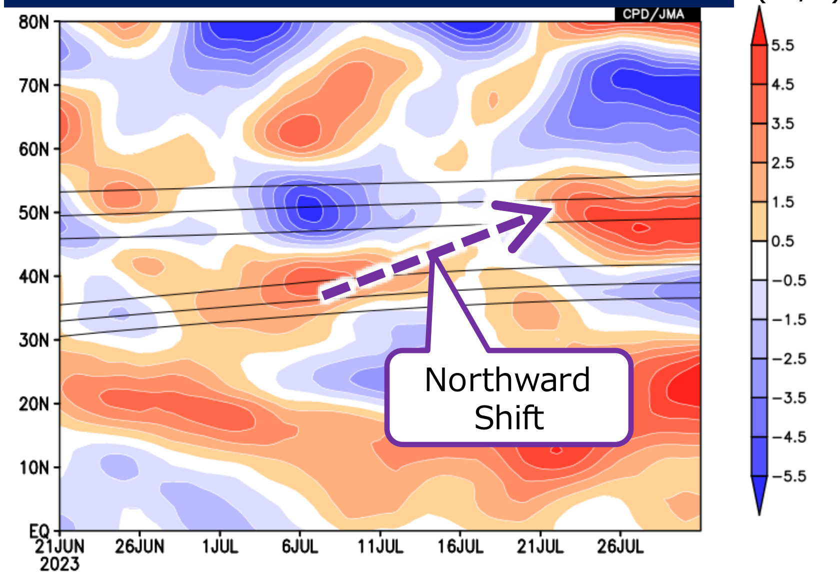


Wavelet of OLR anomalies averaged over 10S-25N, 110E-180 during a period of MJJAS 2023

◆ Daily OLR anomalies exhibited the variability with a period of 10–20 days, consistent with the dominant intra-seasonal oscillation.

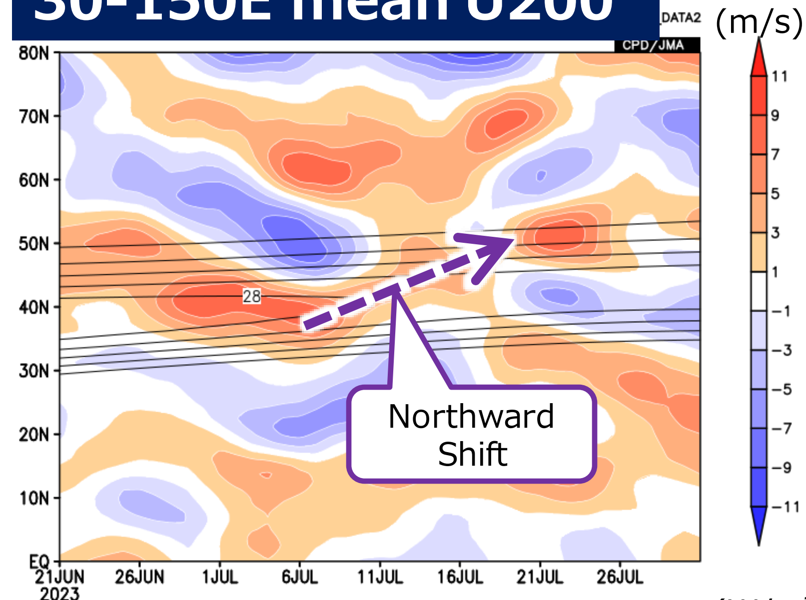
Variability of the Subtropical Jet

Zonally-averaged U200

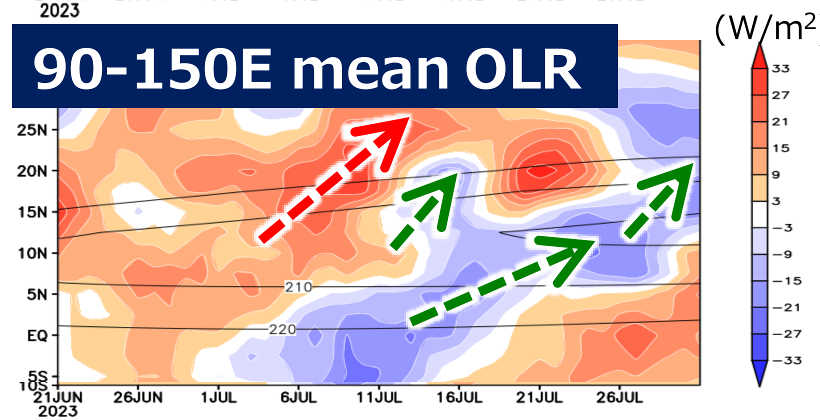


Contour: Climatology (interval: 4m/s interval)
Shading: Anomalies

30-150E mean U200

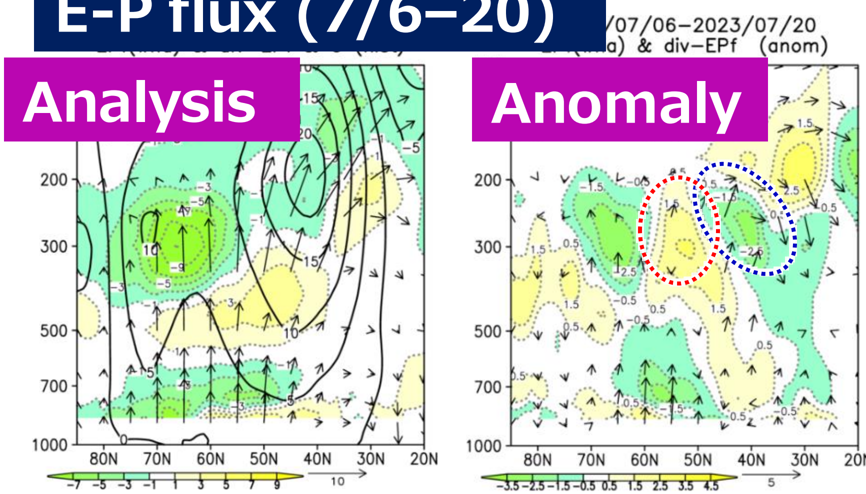


90-150E mean OLR



Contour: Climatology (interval: 10W/m² interval)
Shading: Anomalies

E-P flux (7/6–20)



- In mid-July, the subtropical jet shifted northward in association with westerly acceleration due to wave-mean flow interaction and northwestward migration of enhanced convection.

Appendix.

Time-Latitude Cross Section of SST, Thickness, Moisture

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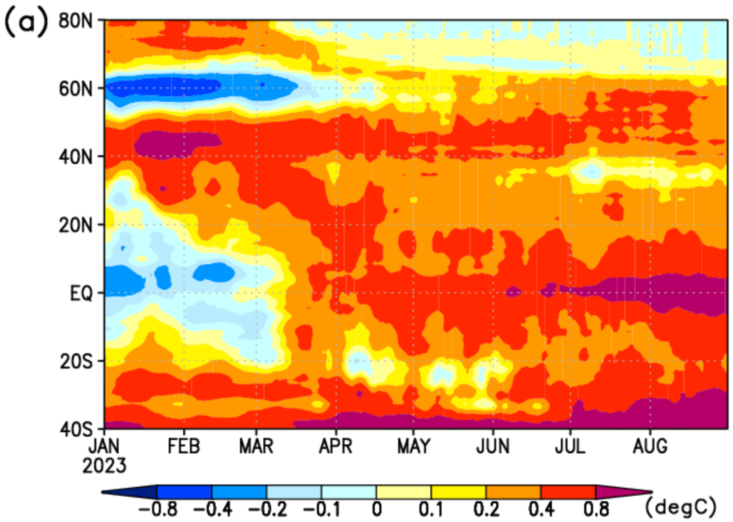
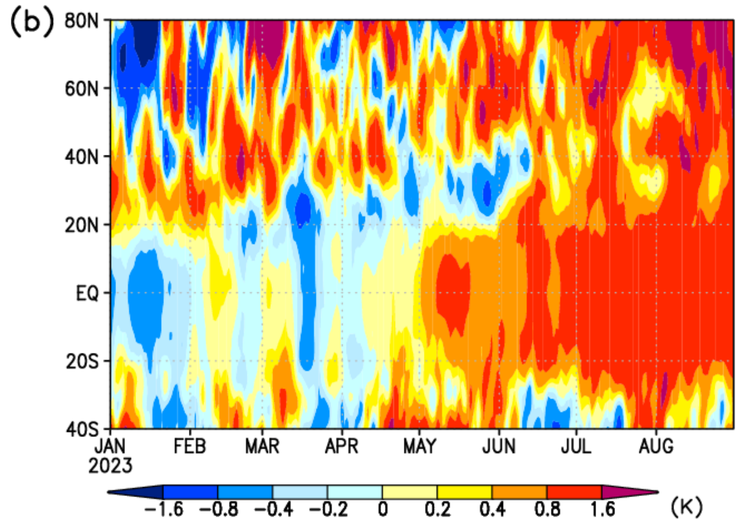
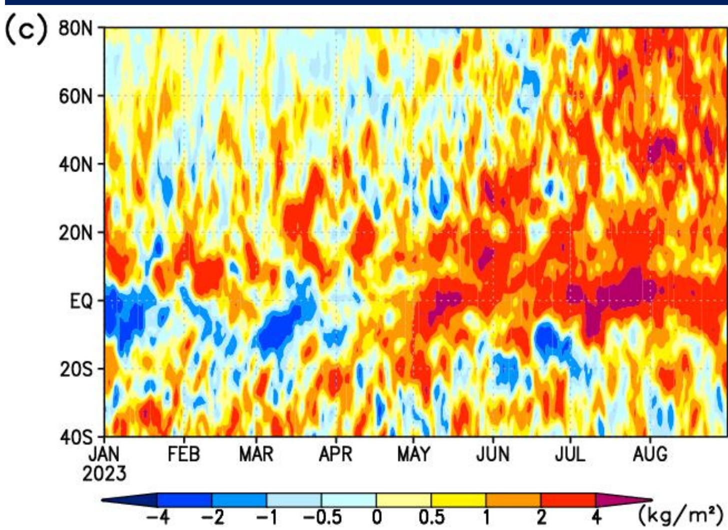
SST anom.



Thickness Temperature anom.



Precipitable Water anom.



- In association with the developing El Niño, SST and air thickness significantly increased from spring onward.
- From spring to summer, higher-than-normal thickness and moisture were distributed in the tropics, and they extended toward the Northern Hemisphere extra-tropics.
- A wide range of high temperature in the N.H. extra-tropics may be partly associated with the greenhouse effect due to rich moisture.