Climate Analysis Information

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Tokyo Climate Center (TCC)
Japan Meteorological Agency (JMA)

Outline

1. Introduction to climate analysis information
2. Climate system monitoring and analysis
   - Basic knowledge
   - Activities at JMA
3. Example of climate analysis information

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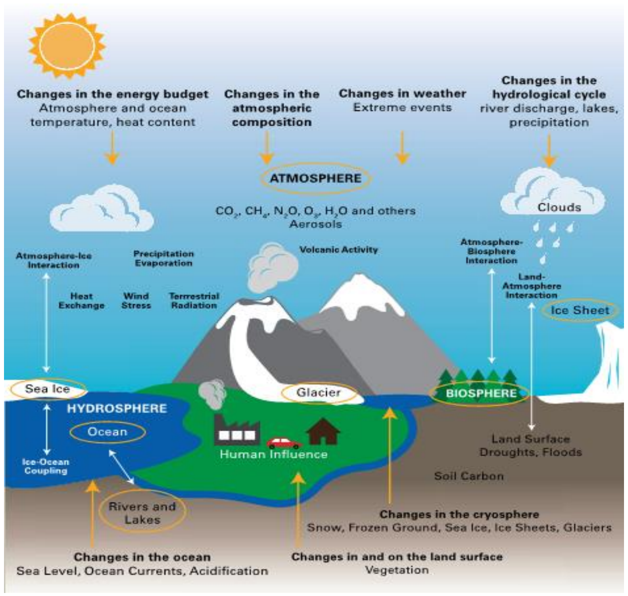
Climate and climate system

- **Climate**: The average weather conditions over a long period of time.
  - The statistics of meteorological elements such as temperature, rainfall, wind, atmospheric pressure…
- **Climate system**: Atmosphere, ocean, land, snow-ice, biosphere …
  - Each component of the climate system varies due to its internal process and interactions with other components.
  - The climate system is very complicated.



Key components of climate system and interactions (WMO 2019)

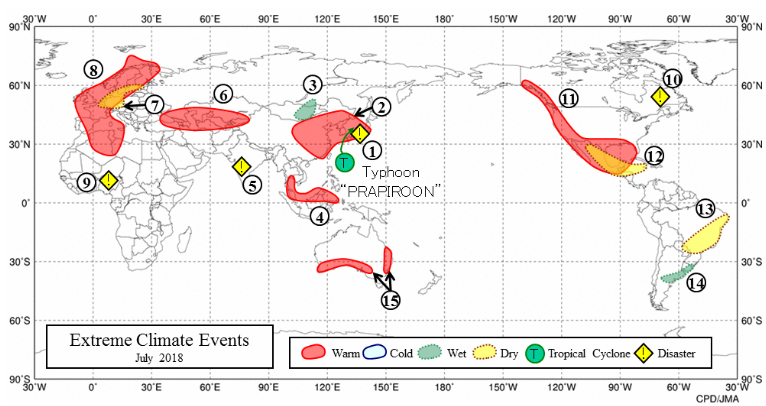
Background

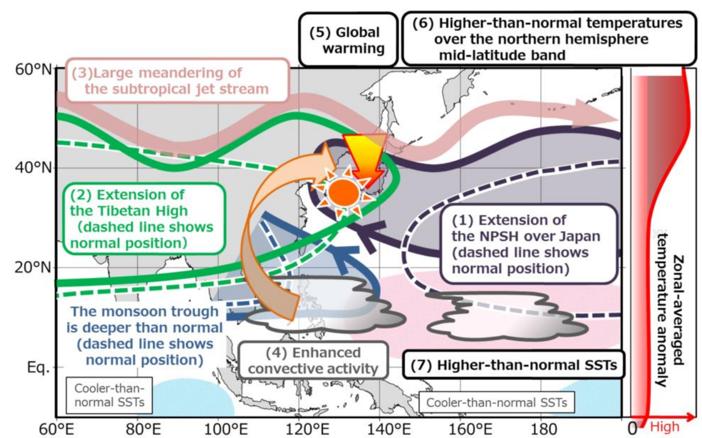
- The climate system has strong impact on socio-economic activities in the world through extreme climate events (e.g., heat/cold waves, droughts and heavy rainfall).
- It is important for society and people to appropriately deal with climate variability and extreme climate events for maximizing climate benefits and minimizing climate risks.

- It is necessary for us to understand present climate conditions, backgrounds and factors, and to prepare for possible impact in the future.

Mission

- National Meteorological and Hydrological Services (NMHSs) are responsible for implementing climate system monitoring services (in addition to climate prediction services) including:
  - Diagnosing and assessing conditions of the climate system.
  - Providing scientifically accurate climate information and products to the public timely and in appropriate formats.





Primary factors behind the unprecedentedly hot conditions observed from mid-July 2018 onward

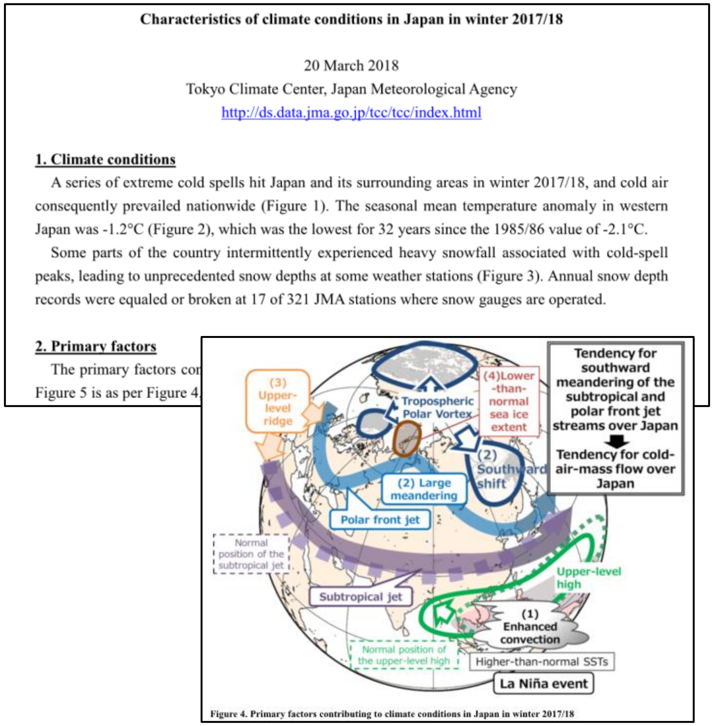
Type of information

1. Information for non-experts

- Easy-to-understand information that is summarized and interpreted without jargon for decision making,
- Tailored information based on users' needs.

2. Information for experts

- Information requiring special and professional knowledge to be understood,
- Detailed information that includes climate system conditions associated with climate events and factor analysis.


Characteristics of climate conditions in Japan in winter 2017/18

20 March 2018
Tokyo Climate Center, Japan Meteorological Agency
http://ds.data.jma.go.jp/tcc/tcc/index.html

1. Climate conditions

A series of extreme cold spells hit Japan and its surrounding areas in winter 2017/18, and cold air consequently prevailed nationwide (Figure 1). The seasonal mean temperature anomaly in western Japan was -1.2°C (Figure 2), which was the lowest for 32 years since the 1985/86 value of -2.1°C.

Some parts of the country intermittently experienced heavy snowfall associated with cold-spell peaks, leading to unprecedented snow depths at some weather stations (Figure 3). Annual snow depth records were equaled or broken at 17 of 321 JMA stations where snow gauges are operated.

2. Primary factors

The primary factors co
Figure 5 is as per Figure 4.

Figure 4. Primary factors contributing to climate conditions in Japan in winter 2017/18

Basic structure of the information

1. Surface climate conditions and impacts
2. Characteristics of atmospheric circulation directly contributing to the surface climate conditions
3. (if possible) Primary factors associated with the characteristic atmospheric circulation

Procedure

- **Analyzing**

Step 1 : Assess surface climate conditions and impacts.

Step 2 : Identify atmospheric circulation directly contributing to the targeted surface climate conditions.

Step 3 : Investigate the possible factors associated with the identified atmospheric circulation directly contributing to the targeted surface climate conditions.

- **Producing information**

- Information for non-experts : Step 1 and summary of Steps 2 and 3.
- Information for experts : Step 1, Step 2 and Step 3.

Information on specific climate events (TCC website)

https://ds.data.jma.go.jp/tcc/tcc/products/clisys/reports/index.html

気象庁 Japan Meteorological Agency

Tokyo Climate Center
WMO Regional Climate Center in RA II (Asia)

WMO

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HOME > Climate System Monitoring > Reports on specific events

Reports on specific events

Reports on extreme climate events and summary reports on the Asian summer/winter monsoon are available at this webpage.

Latest Reports

Asia-Pacific

[Notice (11 April 2019)] Figures 11 and 12 in the article regaring "Summary of the 2018 Asian Summer Monsoon" were found to be those for the year 2017. On 11 April 2019, TCC replaced these figures to the correct ones for 2018.

30 November 2018 NEW

- Summary of the 2018 Asian Summer Monsoon (offprint from TCC News No.54)

03 July 2018

- Summary of the 2017/2018 Asian Winter Monsoon (offprint from TCC News No.52)

Japan

22 August 2018

- Primary factors behind the heavy rain event of July 2018 and the subsequent heatwave in Japan from mid-July onward

20 March 2018

- Characteristics of climate conditions in Japan in winter 2017/18

23 February 2018

- Cold waves and heavy snow in Japan from December 2

Previous Reports

2017
2016
2015
2014
2013
2012
2011

Characteristics of climate conditions in Japan in winter 2017/18

20 March 2018
Tokyo Climate Center, Japan Meteorological Agency
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1. Climate conditions

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2. Primary factors

The primary factors contributing the climate conditions detailed above are illustrated in Figure 4.

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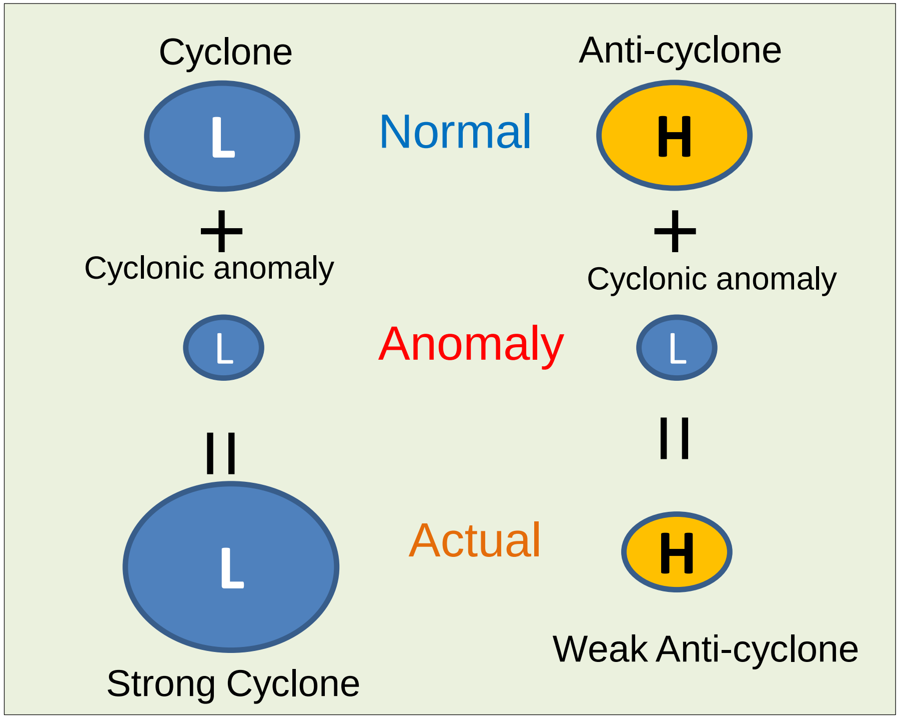
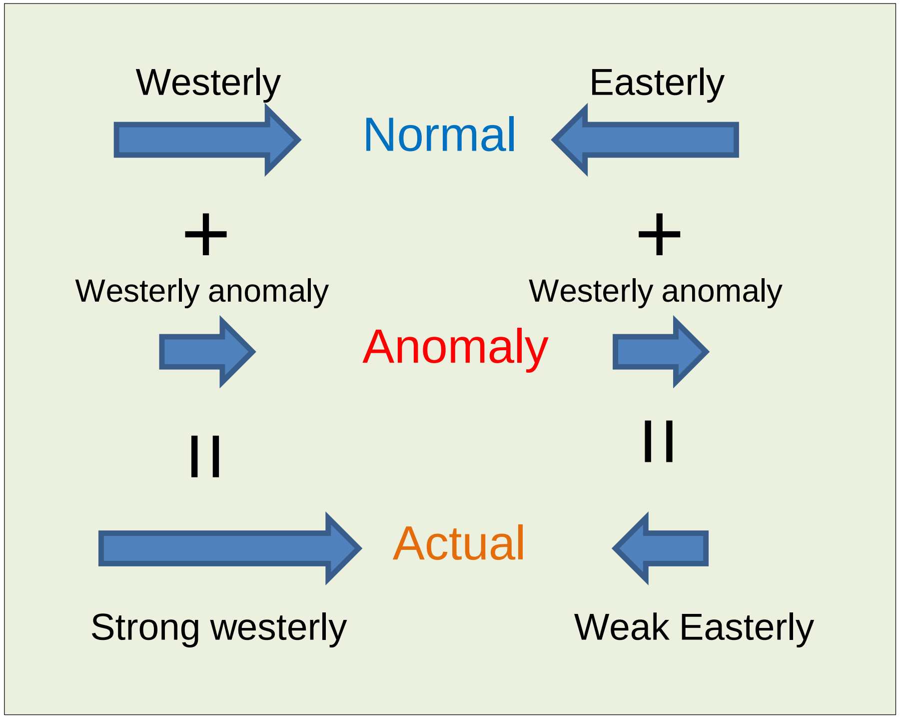
Climatological normal and anomaly

Normal is the average over a sufficiently long period (typically 30 years).

Anomaly is the deviation of an observed atmospheric or oceanic condition from the climatological normal.



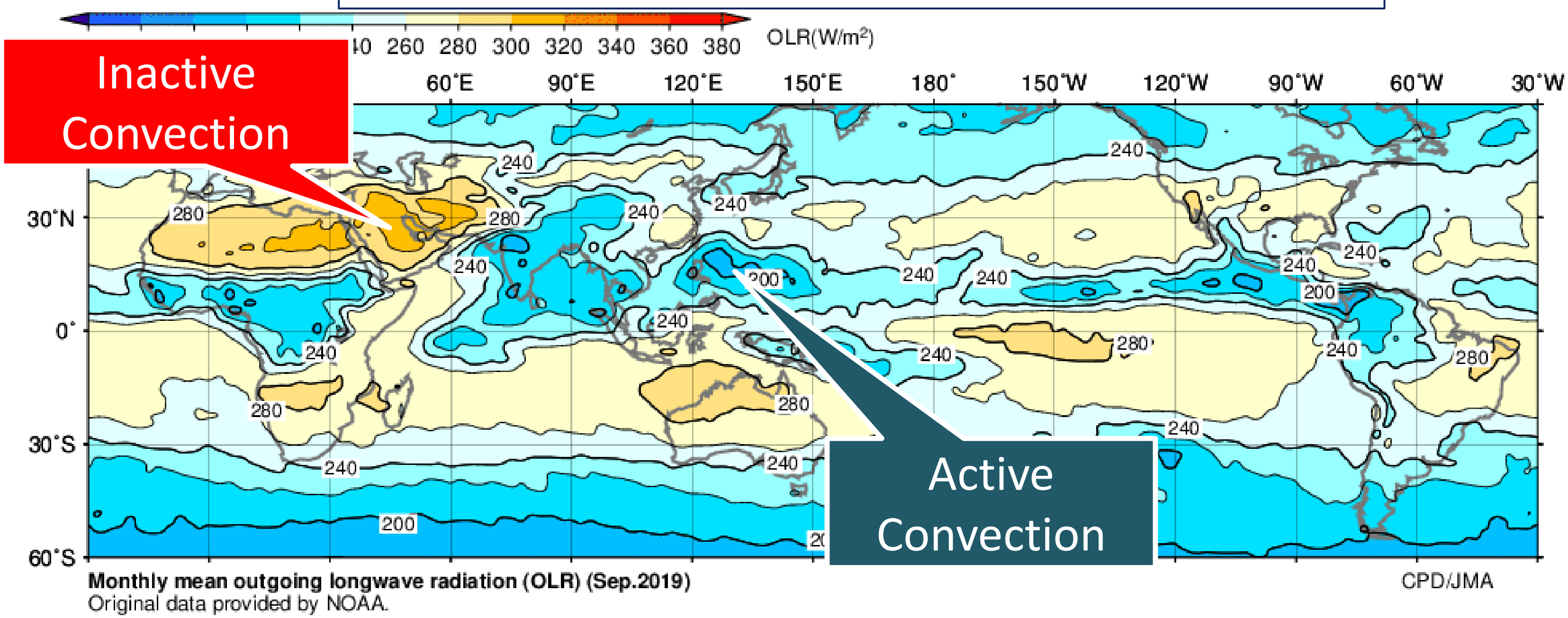


Same anomalies, but different meanings.

Outgoing Longwave Radiation (OLR)

- OLR represents the strength of longwave radiation to space from...
  - the earth's surface under clear sky conditions
  - the top of clouds under cloudy conditions
- It can be assumed that lower (higher) values of OLR in the Tropics indicate active (inactive) convection.

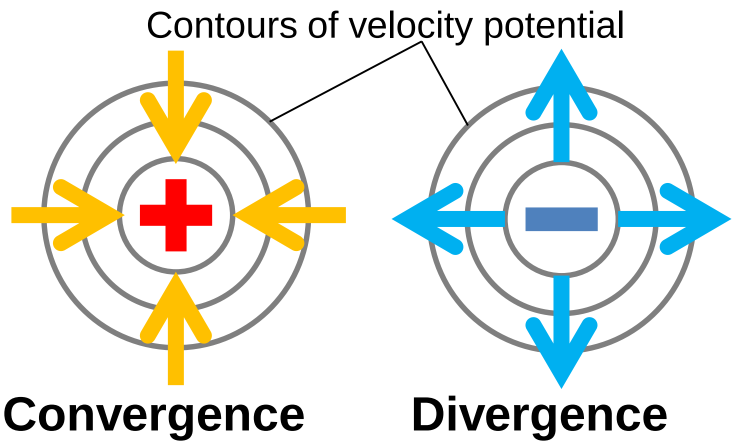
Monthly-mean OLR in September 2019



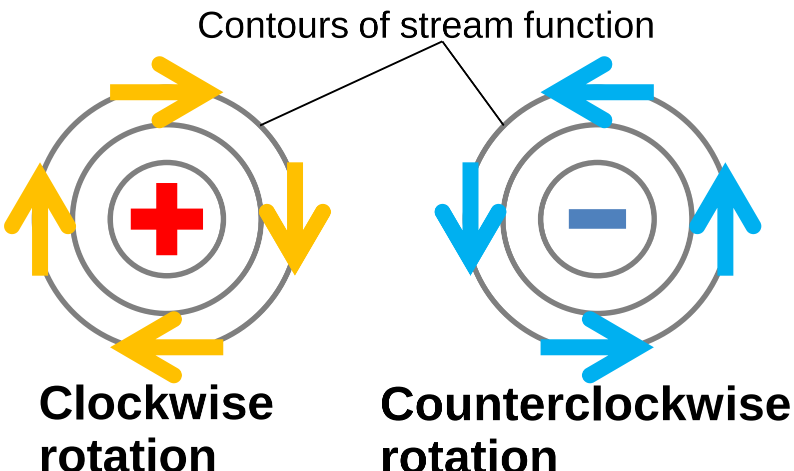
Velocity potential and stream function

- Air flow can be decomposed into a divergent part and a rotational part under the assumption of perfect fluid.
- Velocity potential (χ) indicates the divergent part.
  - Divergent wind blows across contours of it, from areas of low to high, regardless of the hemisphere.
  - Strong divergence at the upper troposphere corresponds to active convection.
- Stream function (ψ) indicates the rotational part.
  - Rotational wind blows parallel to contours of it, with low value to the left, regardless of the hemisphere.
  - Air flow around local maximum (i.e. clockwise) corresponds to anti-cyclonic rotation in the N.H. and cyclonic rotation in the S.H.

Velocity potential (divergent part)

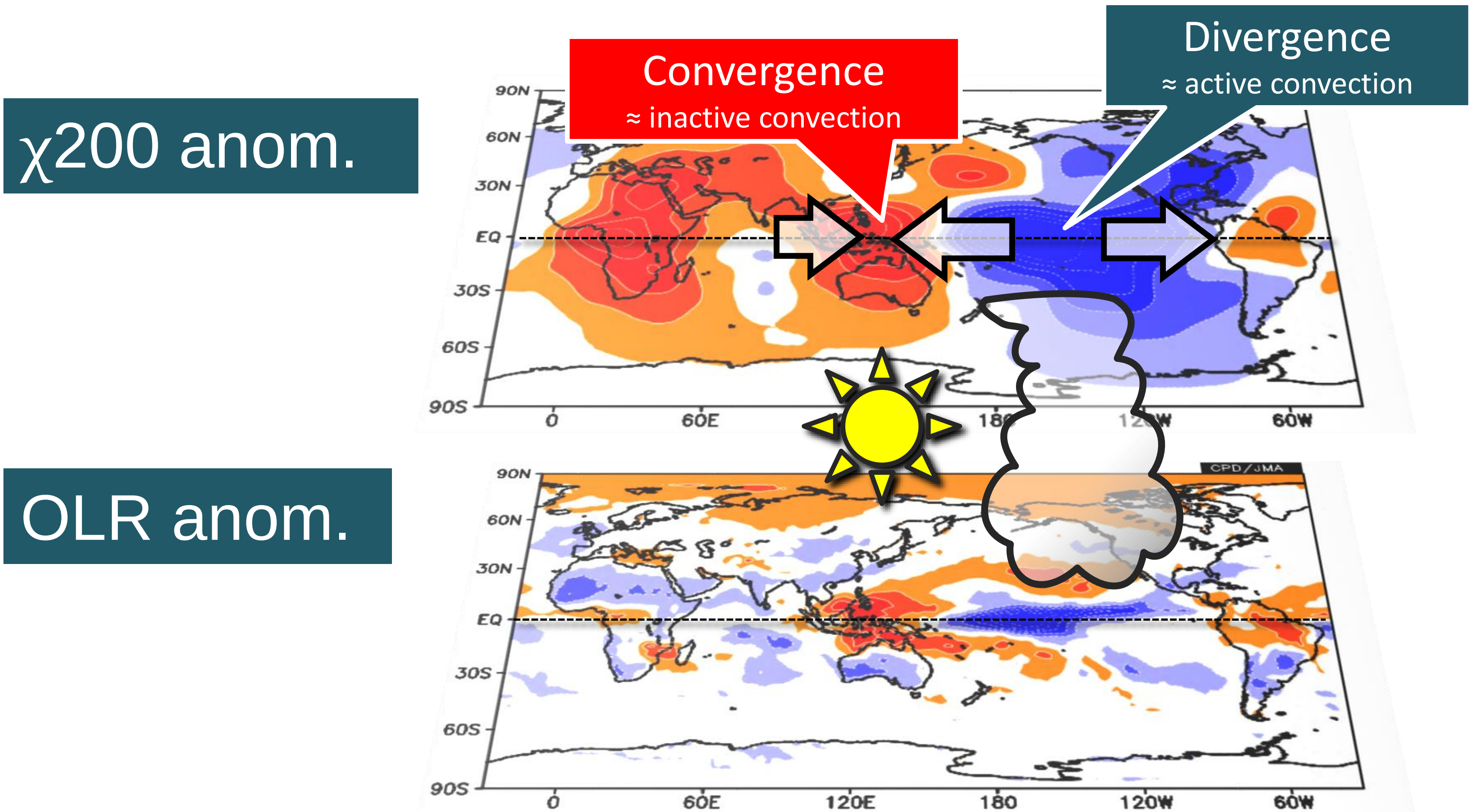


Stream function (rotational part)



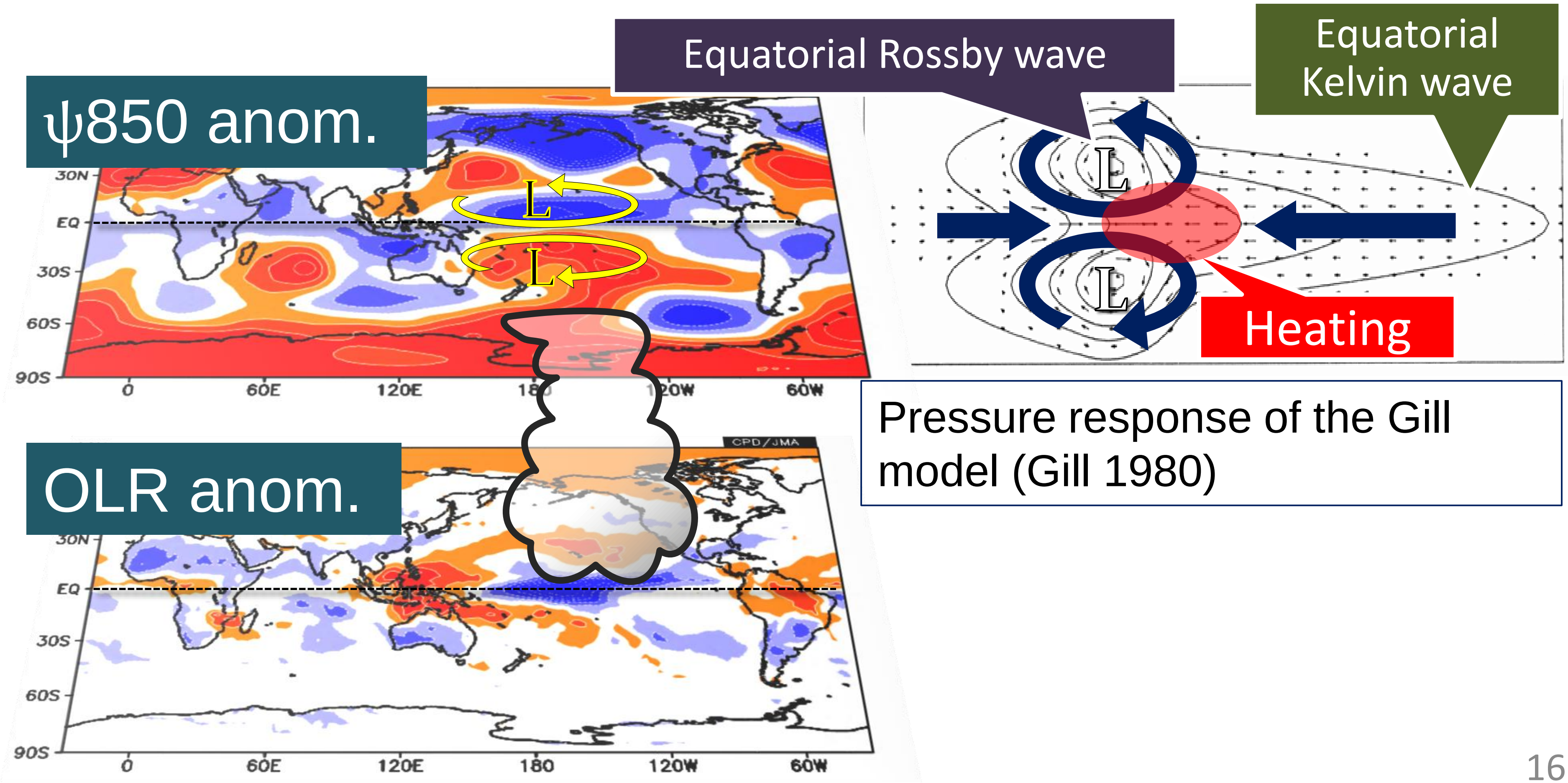
Tropical convection and divergence

- In association with the enhanced (suppressed) convective activity, upper-tropospheric divergence (convergence) anomalies were seen over the central-to-eastern (western) Pacific during El Niño boreal winter 2015/16.



Tropical convection and circulation

- In association with the enhanced (suppressed) convective activity, cyclonic (anti-cyclonic) circulation anomalies straddling the equator are seen, indicating the appearance of the Matsuno–Gill response.

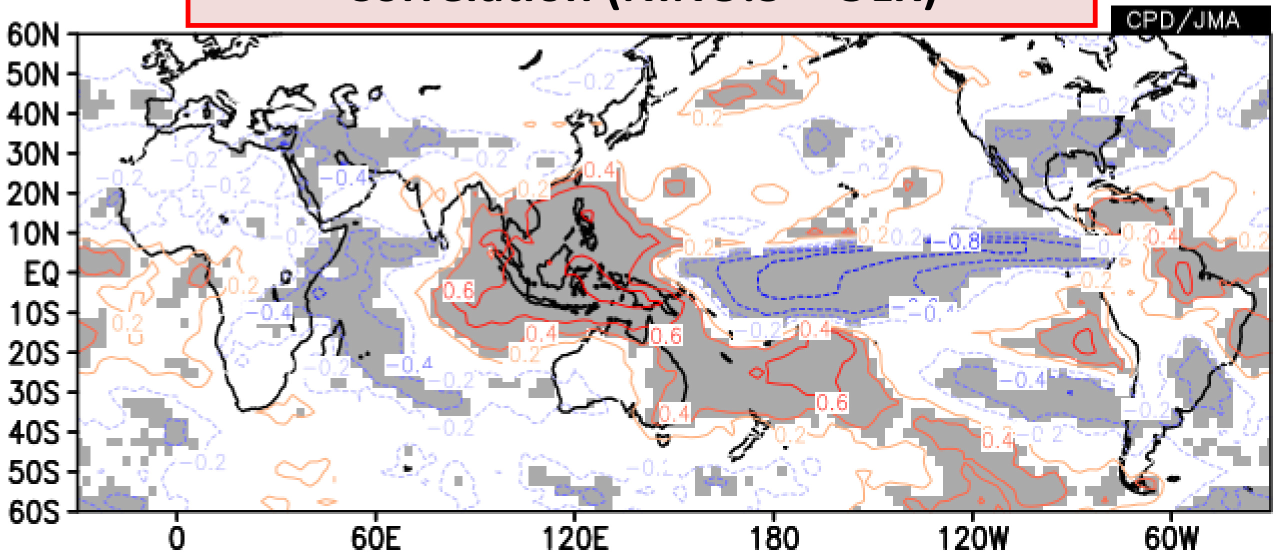


Correlation analysis

- This technique is used to investigate the linear relationship between two variations.
- Correlation coefficients range between -1 and 1. High (low) absolute values indicate strong (little) linear relationship.

r < 0 : Negative correlation
r = 0 : No correlation
r > 0 : Positive correlation

Correlation (NINO.3 – OLR)



Correlation coefficients between NINO.3 SST indices and OLR (Sep. – Nov.)

The base period for the analysis is 1979 – 2018. The grey shading indicates a 95% confidence level. This is drawn by the iTacs.

Regression analysis

- Single regression analysis is used to investigate quantitatively to what extent a response variable is explained by an explanatory variable.
- Regression coefficient shows the anomaly of a response variable in one standard deviation of an explanatory variable.

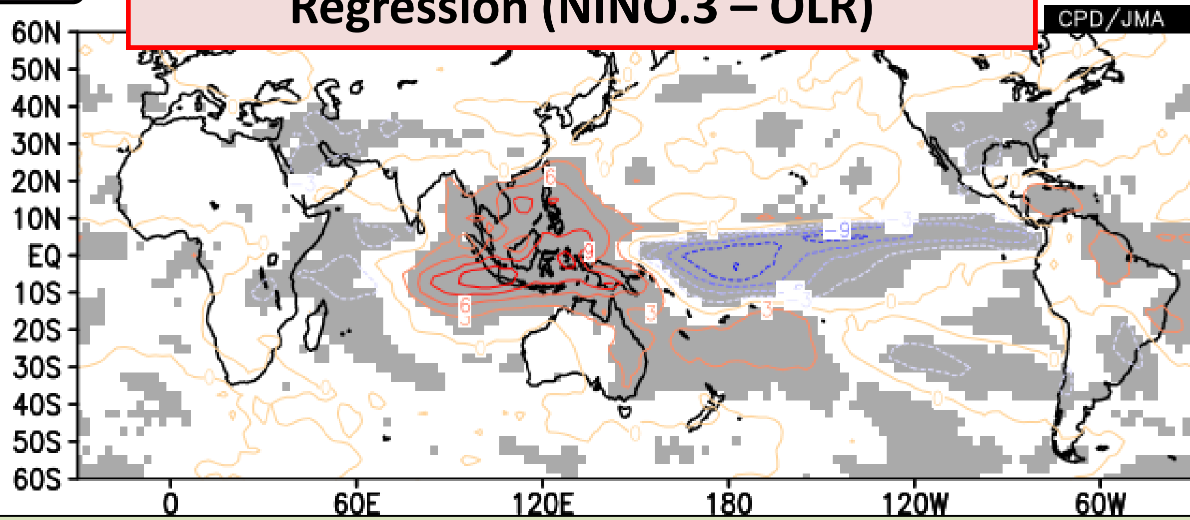
$$y = a x + b$$

Regression coefficient

Intercept

y: Response variable (e.g., stream function)
x: Explanatory variable (e.g., NINO.3 SST index)

Regression (NINO.3 – OLR)



Regression coefficients of OLR (W/m^2) onto NINO.3 SST indices (Sep. – Nov.)

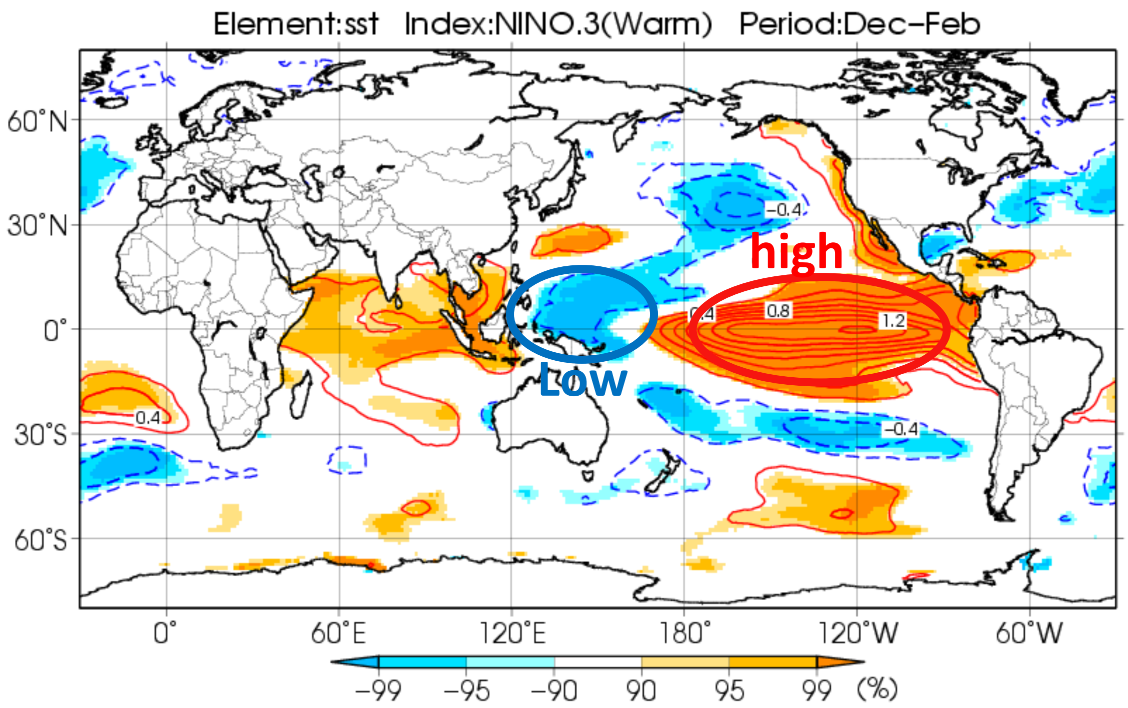
The base period for the analysis is 1979 – 2018. The grey shading indicates a 95% confidence level. This is drawn by the iTacs.

Composite analysis

- Composite analysis is a statistical technique to extract the common characteristics in past events of a targeted phenomenon (e.g., El Niño and La Niña events) from the other phenomena.

SST Composite Map in El Nino Phase (DJF)

Contours: anomaly
Shadings: confidence level
Statistical period: 1958/59 – 2012/13
Composite year : 65/66, 68/69, 69/70, 72/73, 76/77, 82/83, 86/87, 91/92, 97/98, 02/03, 09/10



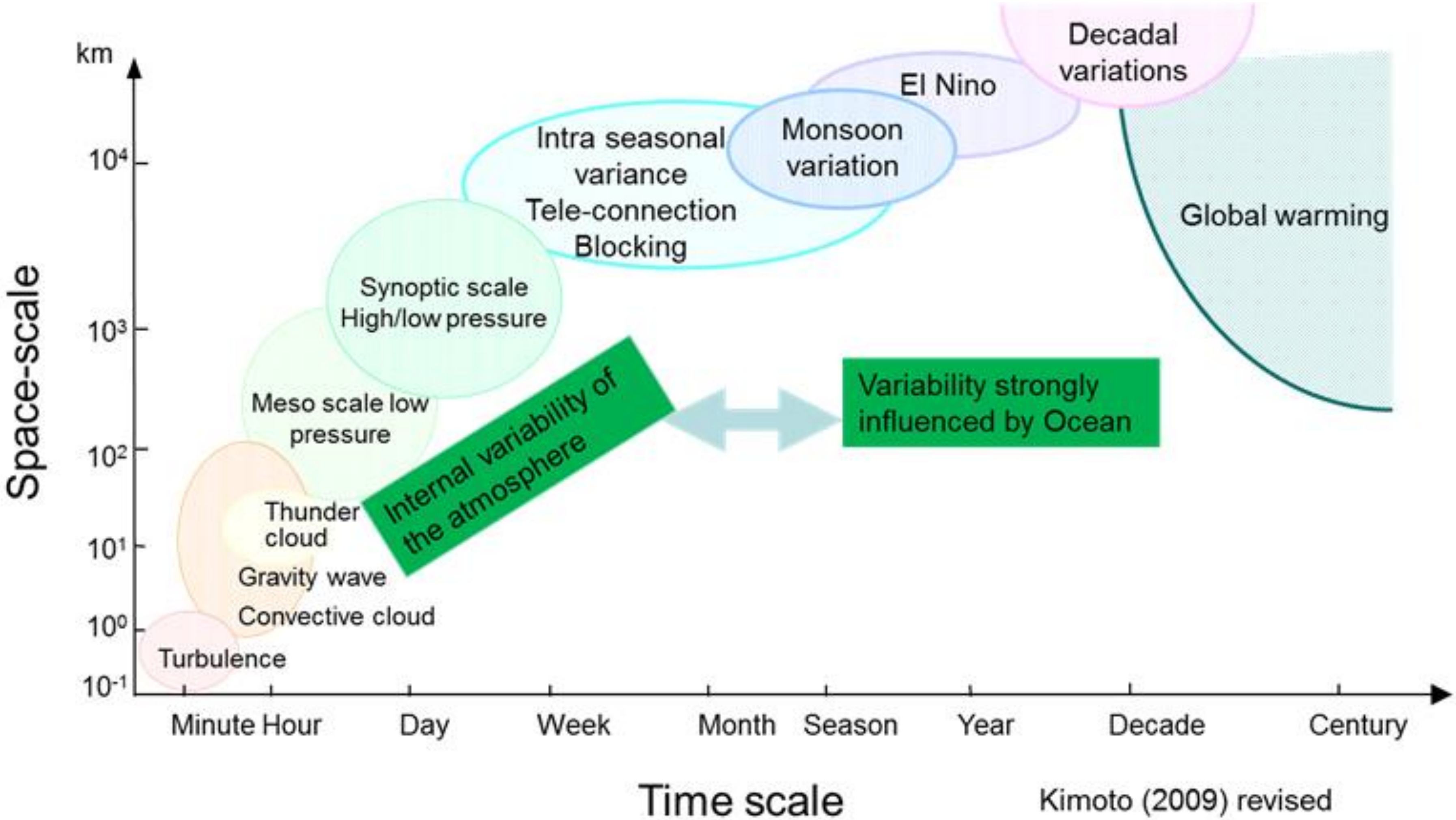
Statistical analysis (brief comments)

- If a certain climate variation does not have a linear relationship with other variation (e.g., El Nino events), composite analysis is useful.

- If a certain climate variation has a linear relationship with other variation (e.g., El Nino events) and there are not enough samples to implement statistically reliable composite analysis, regression and correlation analyses are useful.

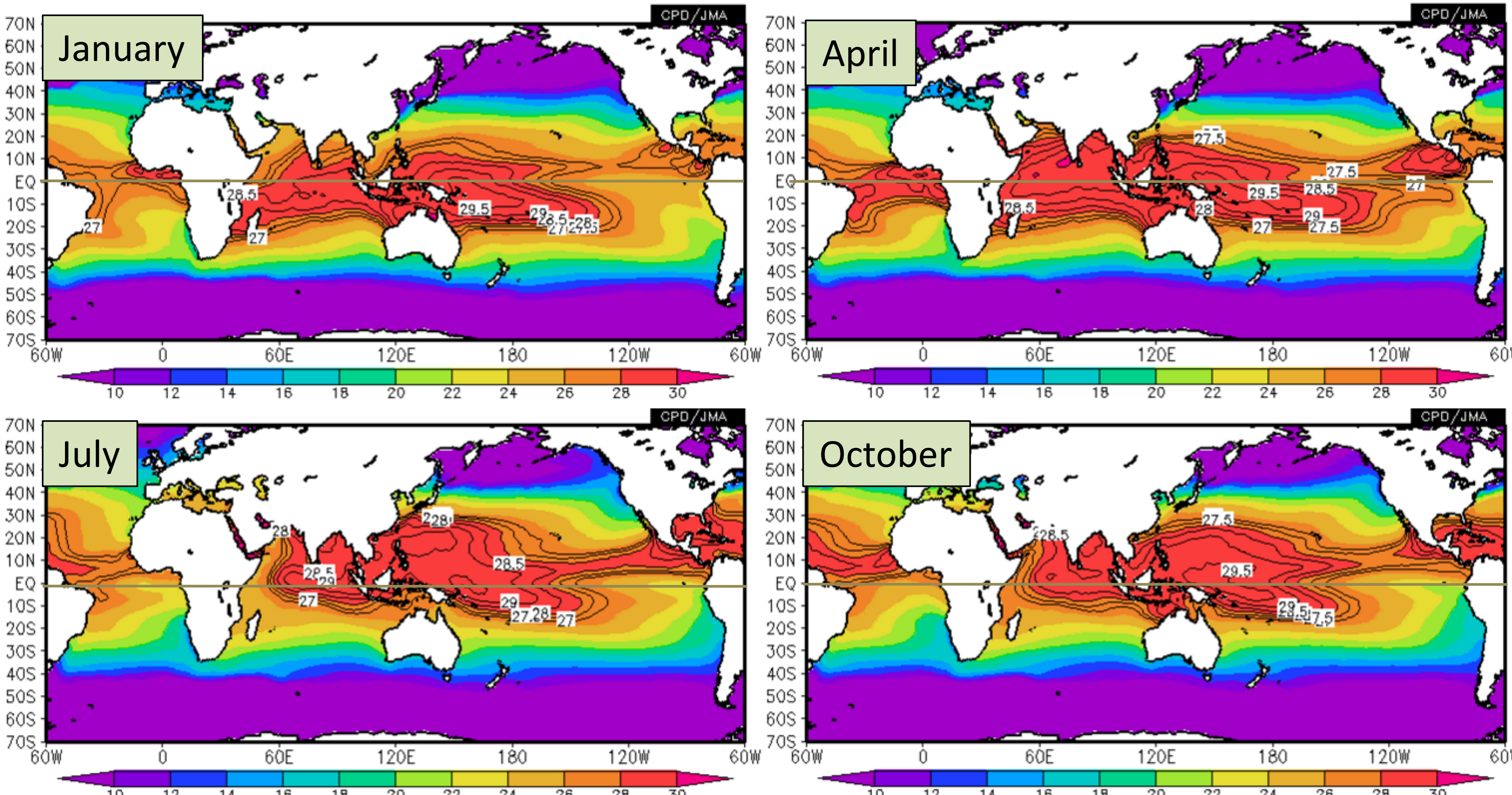
- Keep in mind that statistical results DO NOT ALWAYS give us the physical nature of the target systems or phenomena. Statistics is just a matter of mathematics. We need physical interpretation after statistical analysis.

Temporal and spatial scale of phenomena



Sea surface temperature (SST)

- High SST areas (tropics) migrate meridionally, lagging solar elevation by a month or more.

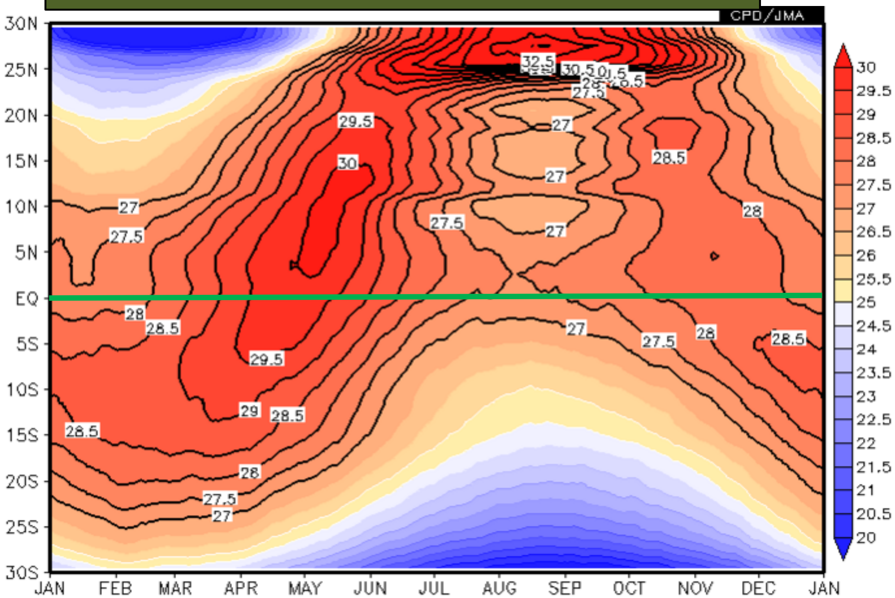


Monthly mean SST (1981 – 2010 average)

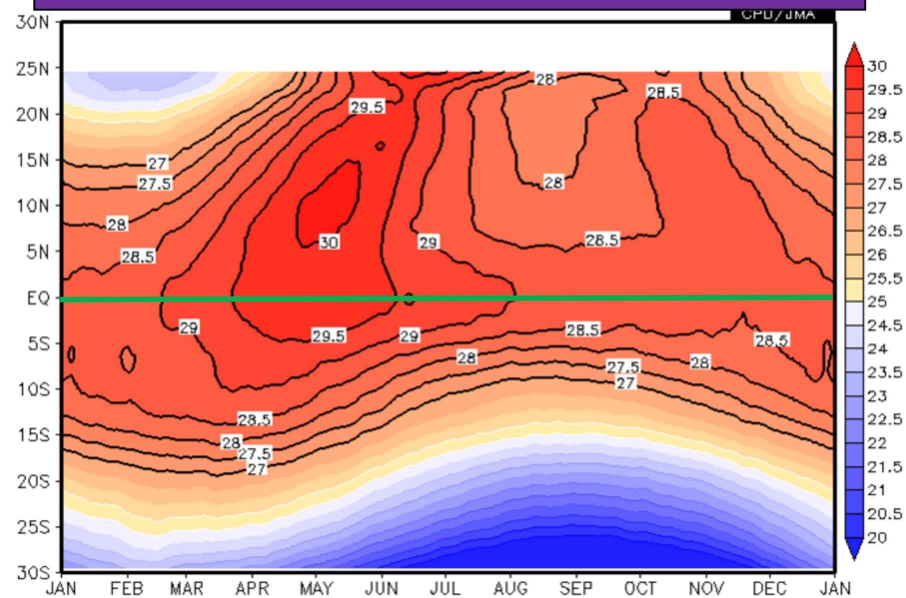
The contour interval is 0.5 ˚C (shown for 27˚C and above).

Annual cycle of SST (Indian Ocean)

Western Indian Ocean (40 – 70˚E)

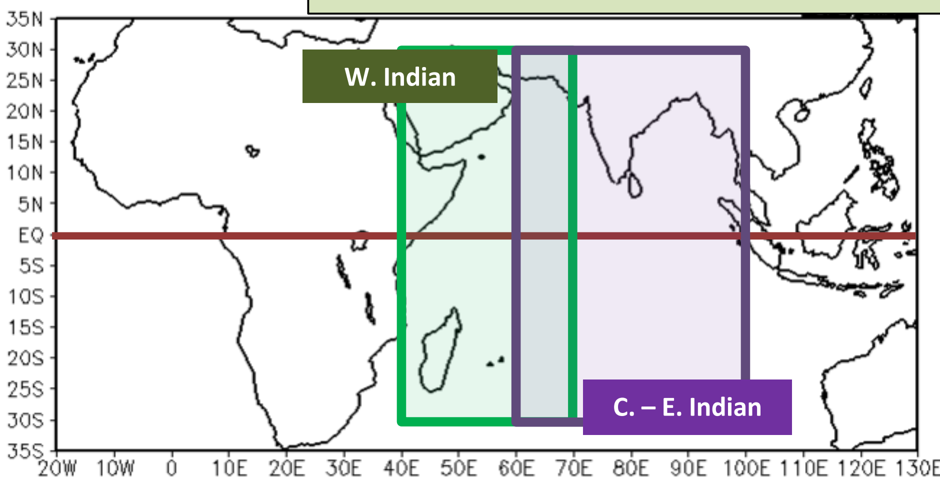


Central – eastern Indian Ocean (60 – 100˚E)

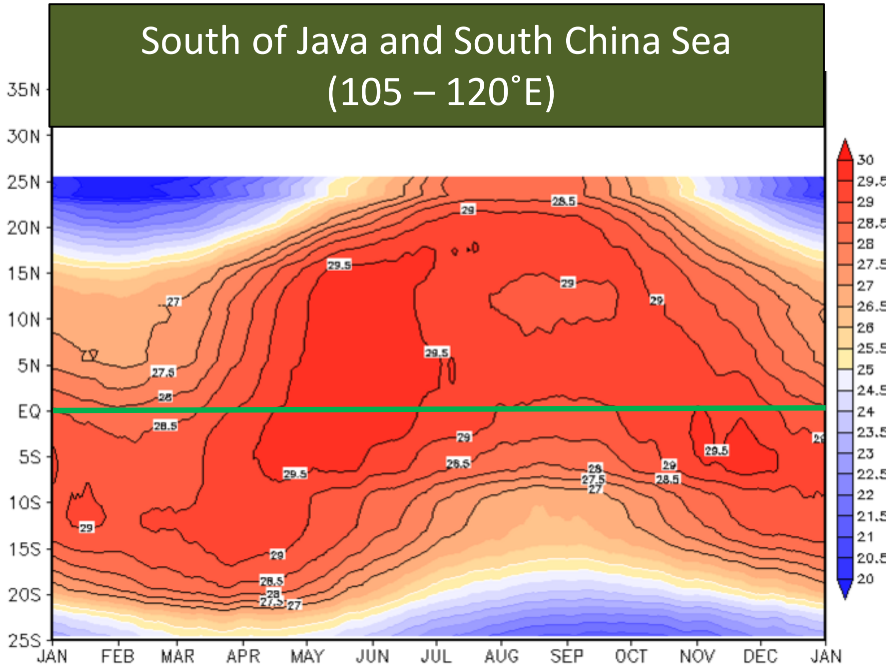


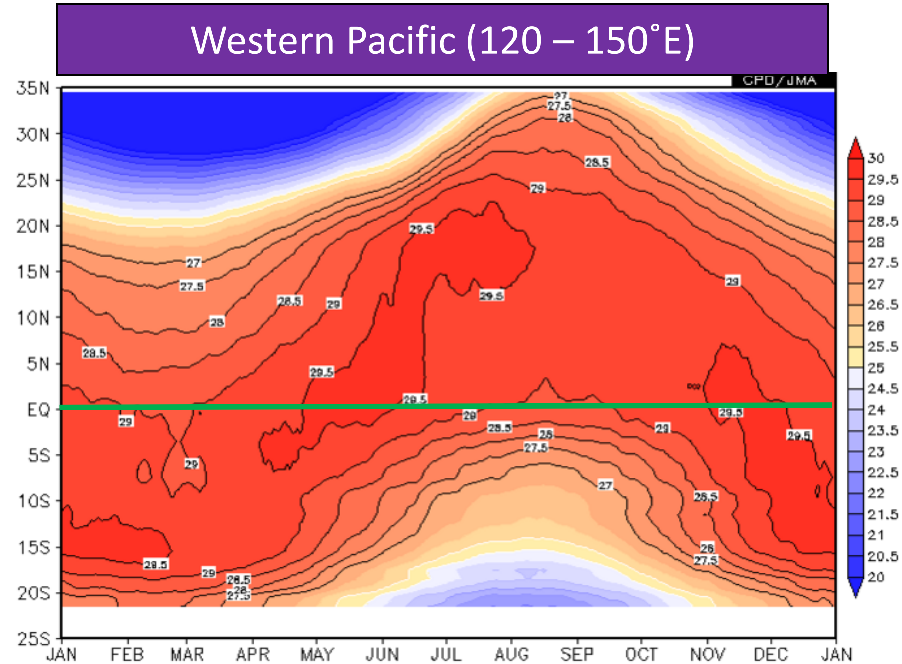
Zonal-average SST (1981 – 2010 average)

The contour interval is 0.5 ˚C (shown for 27˚C and above).



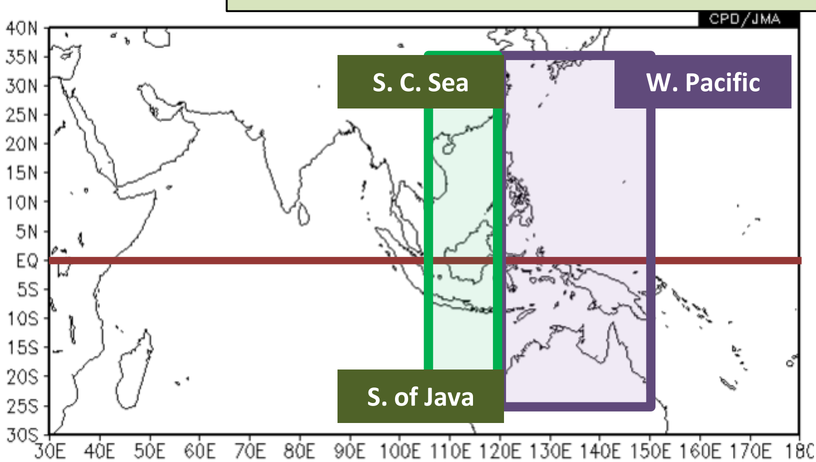
Annual cycle of SST (western Pacific)





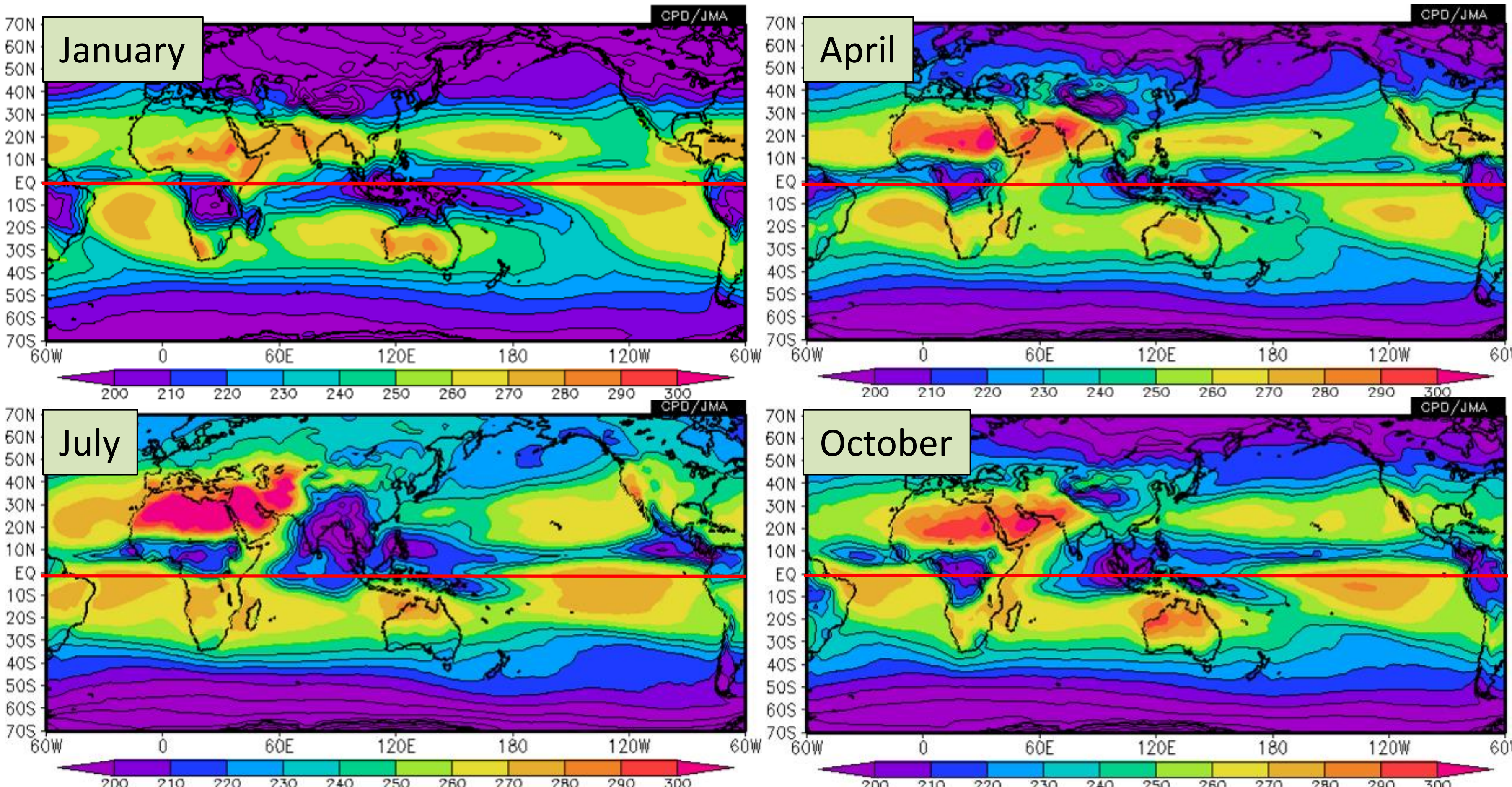
Zonal-average SST (1981 – 2010 average)

The contour interval is 0.5 ˚C (shown for 27˚C and above).



Outgoing Longwave Radiation (OLR)

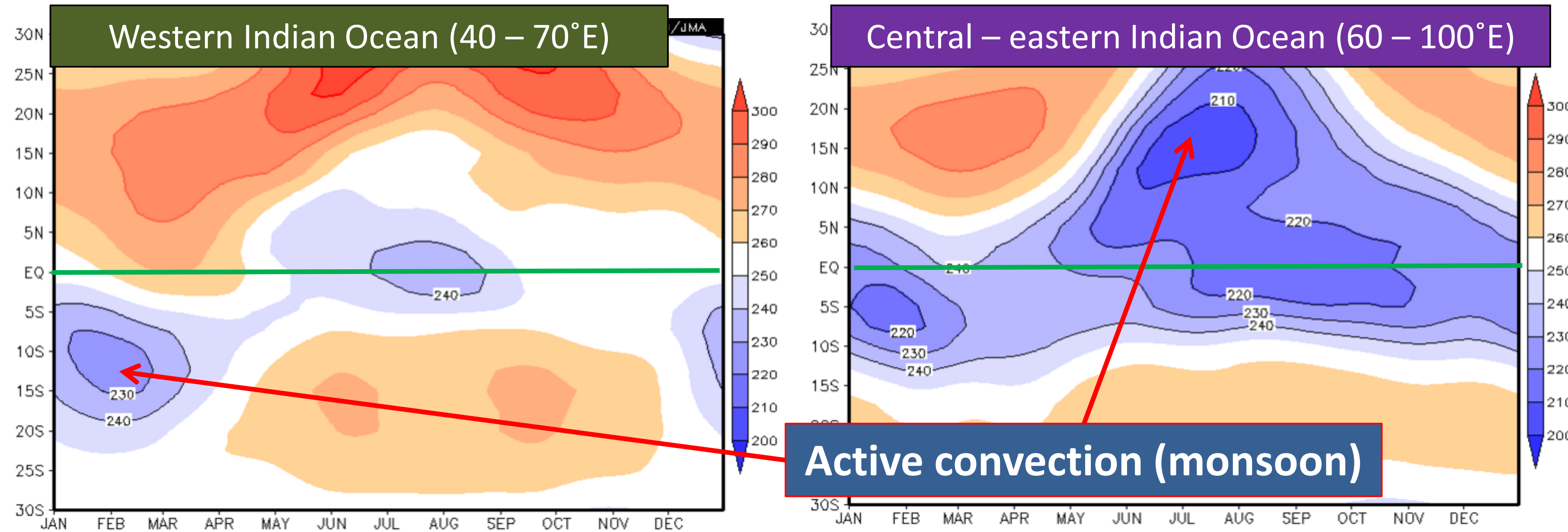
- Low OLR (active convection) areas migrate meridionally (northwest – southeast), generally in line with annual cycle of high SST areas.



<u>Monthly mean OLR (1981 – 2010 average)</u>

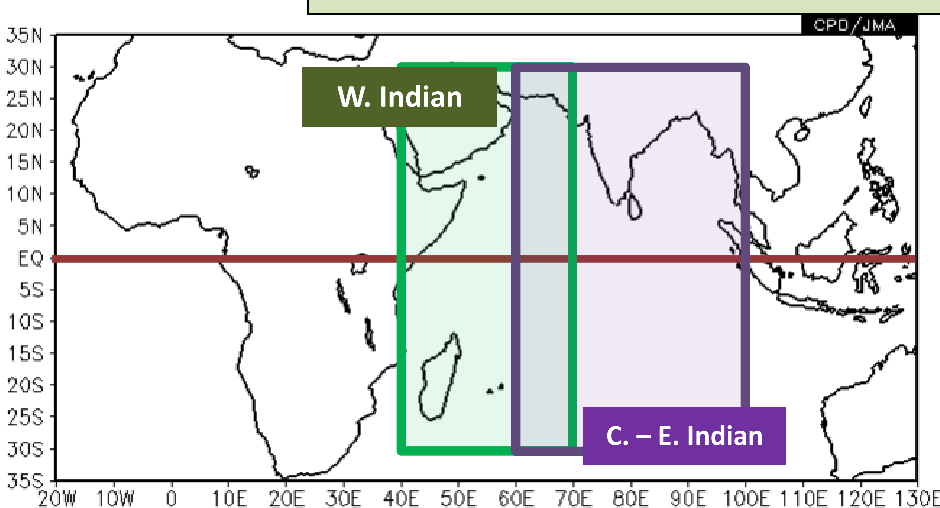
The contour interval is 10 W/m^2 (shown for 240 W/m^2 and below).

Annual cycle of OLR (Indian Ocean)

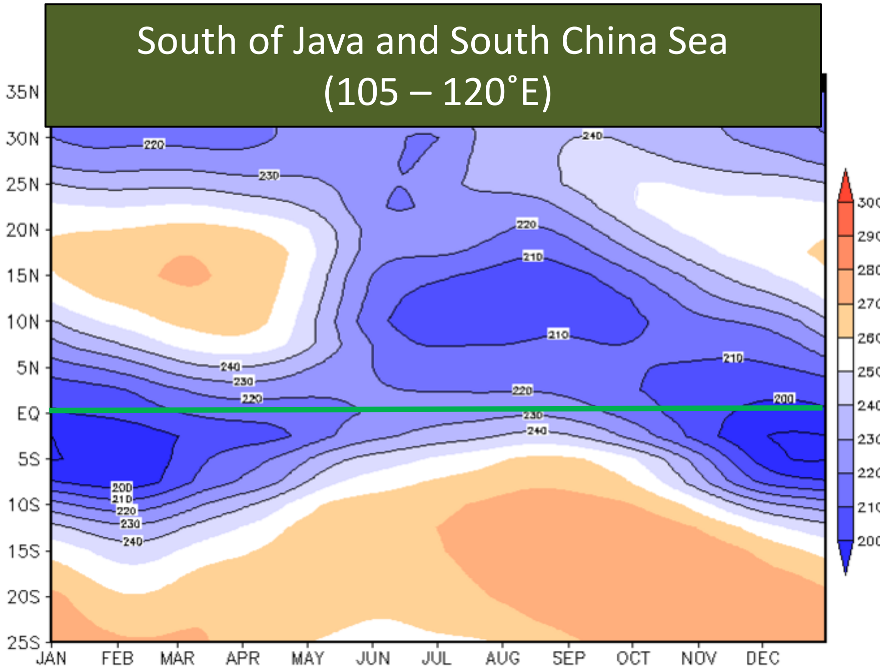


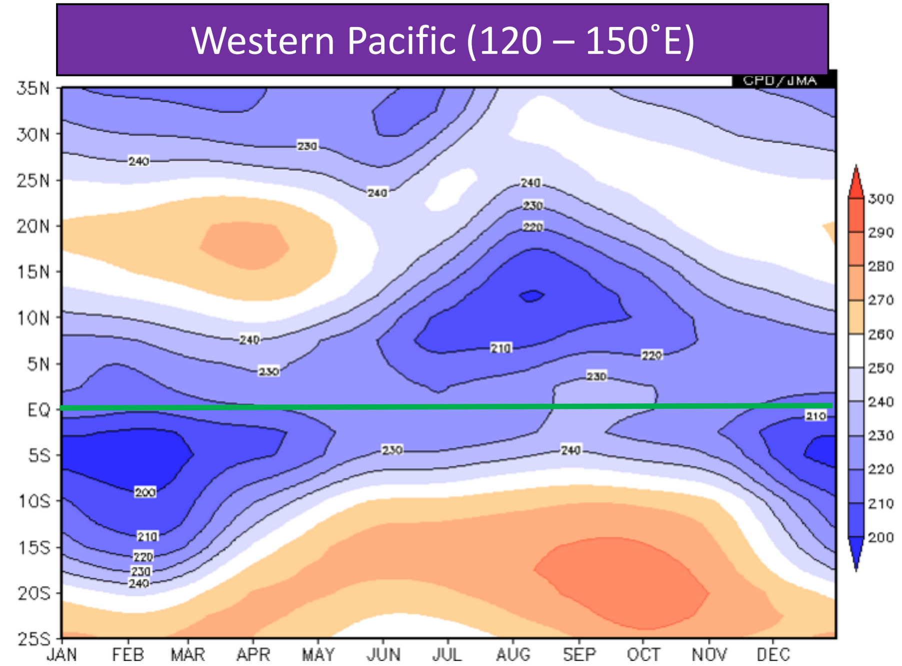
Zonal-average OLR (1981 – 2010 average)

The contour interval is 10 W/m² (shown for 240 W/m² and below).



Annual cycle of OLR (western Pacific)





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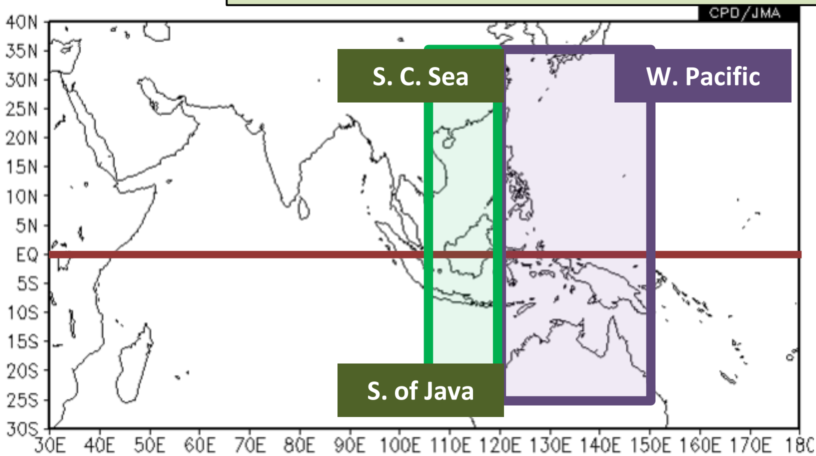
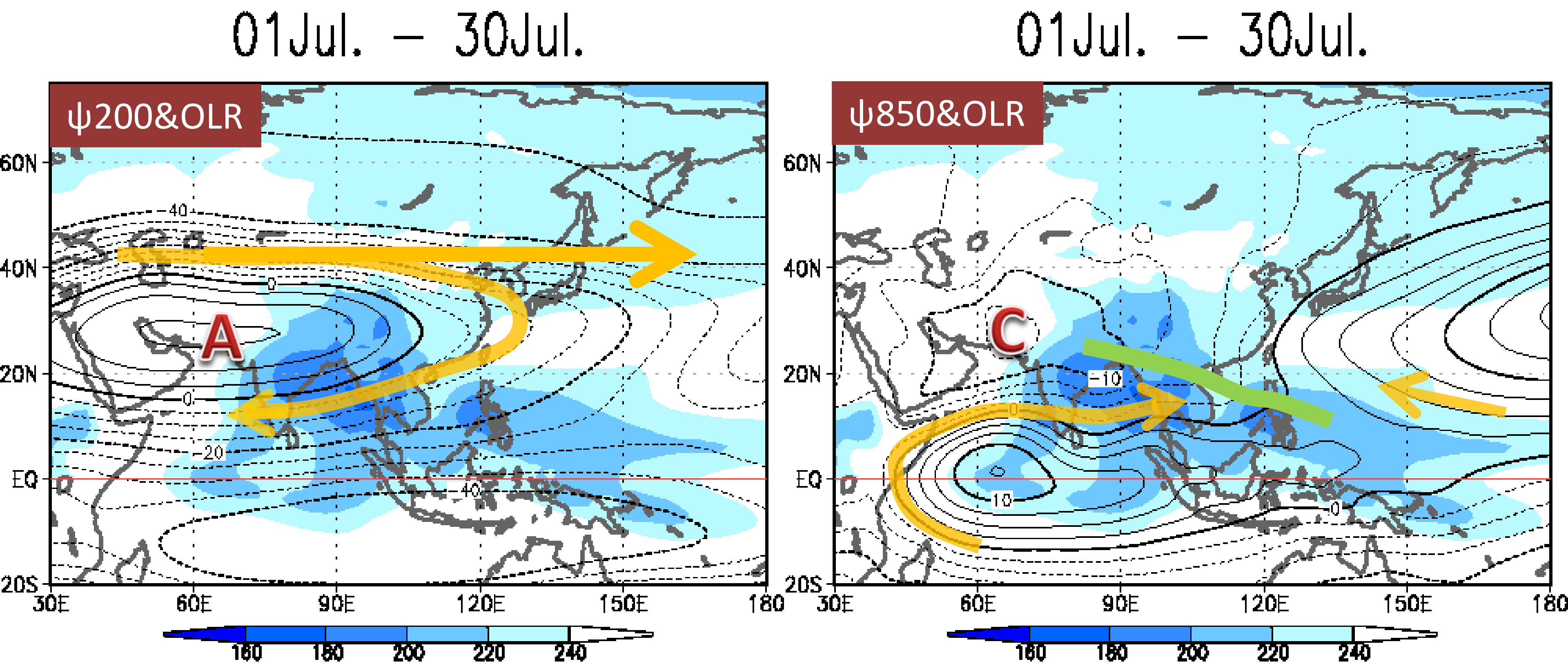


Summer monsoon circulation (1)



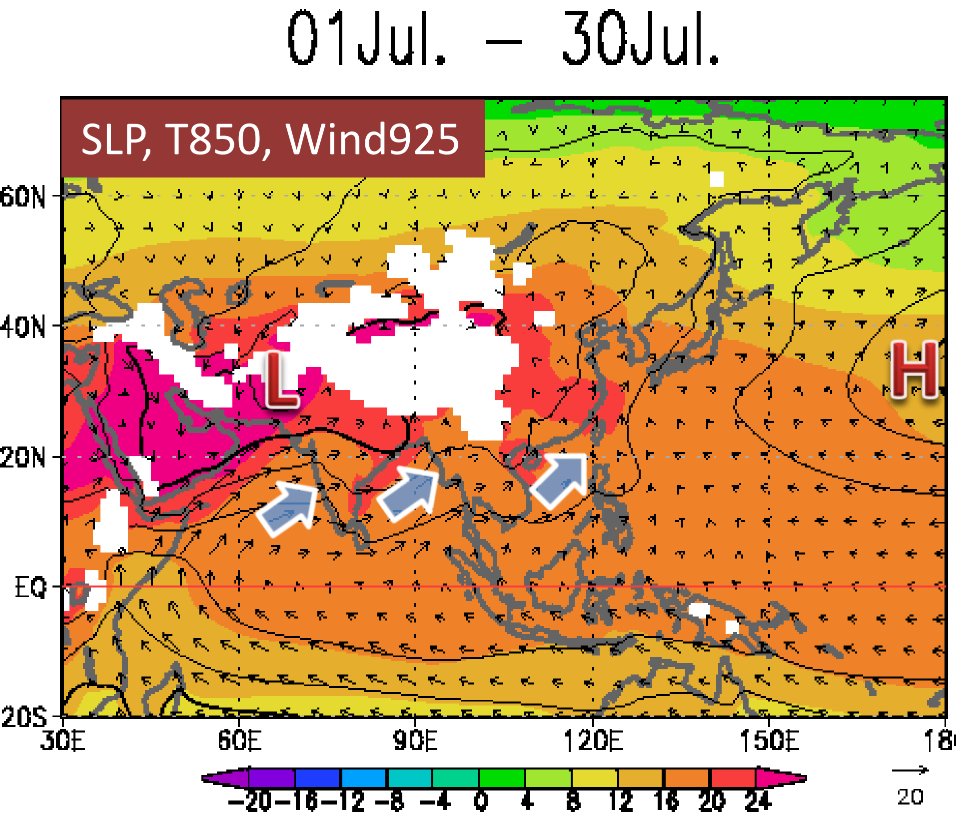
Climatological normals of atmospheric circulation and convection (July)

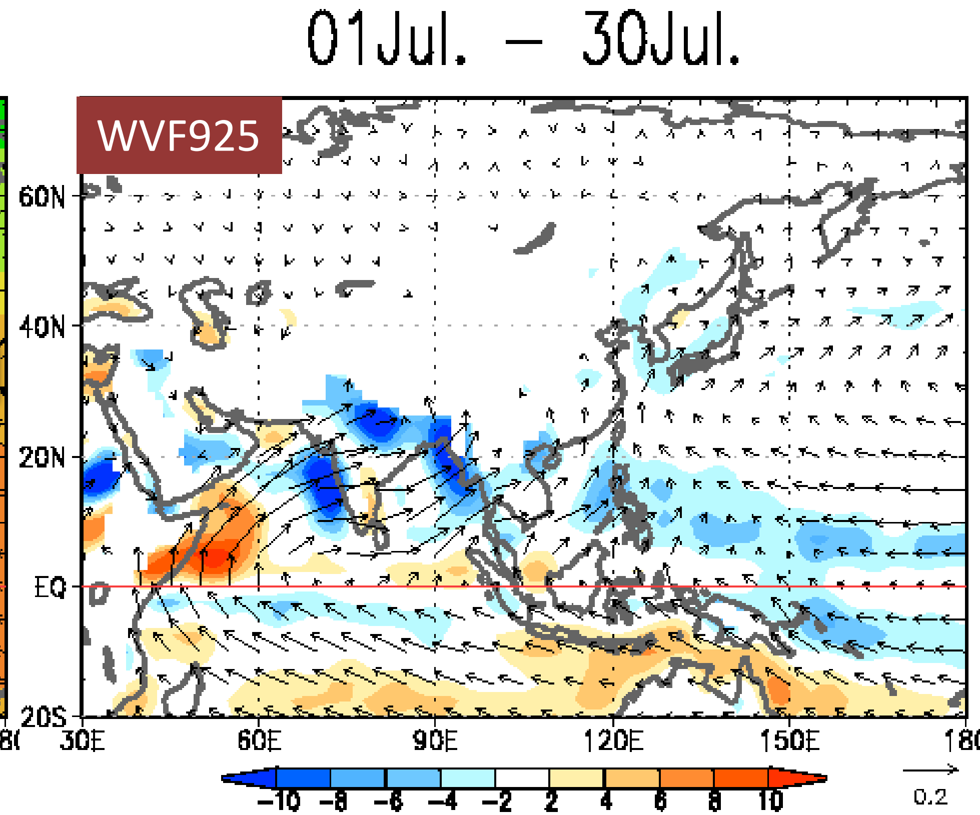
Contours: 200-hPa (left) and 850-hPa (right) stream function

Shading: OLR

Base period for normal: 1981 – 2010

Summer monsoon circulation (2)





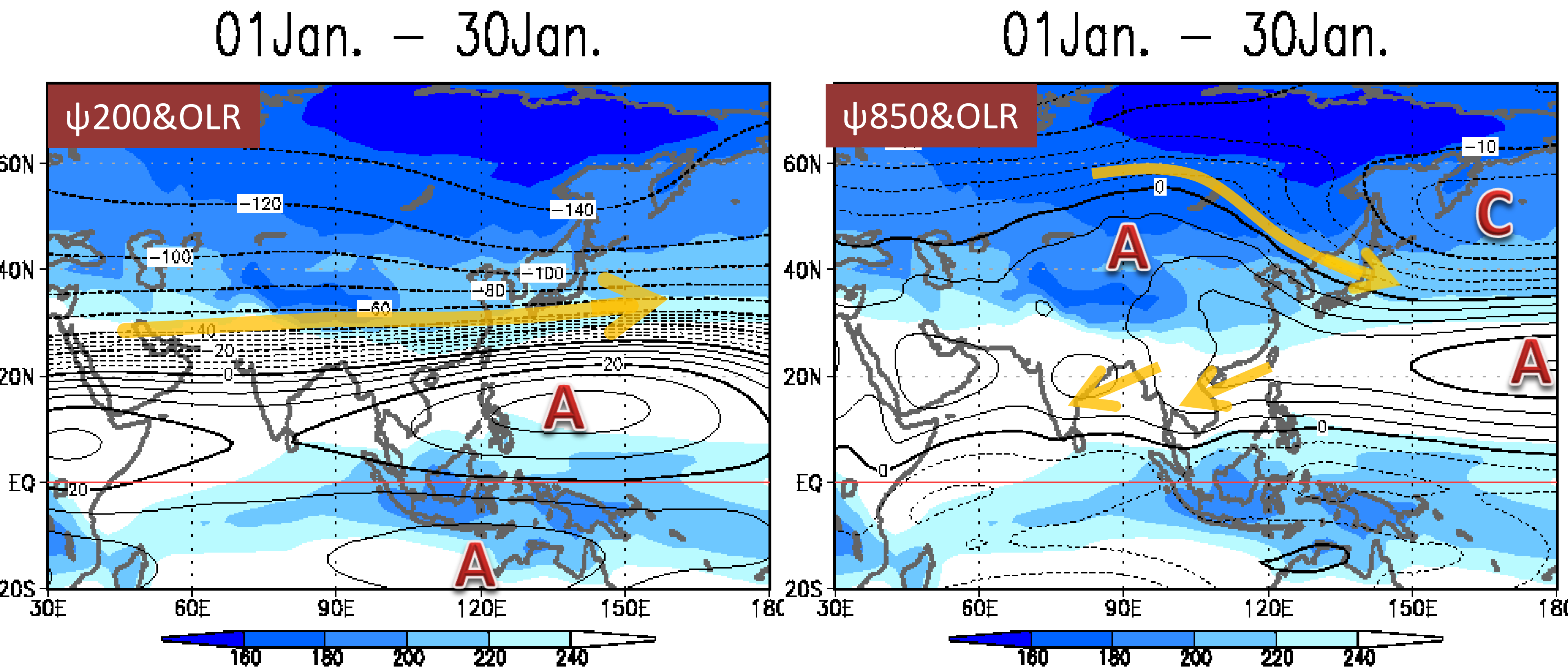
Climatological normals of atmospheric circulation (July)

Left: Sea level pressure (contour), 850-hPa temperature (shading) and 925-hPa wind vectors

Right: 925-hPa water vapor flux (vector) and its divergence/convergence (shading)

Base period for normal: 1981 – 2010

Winter monsoon circulation (1)



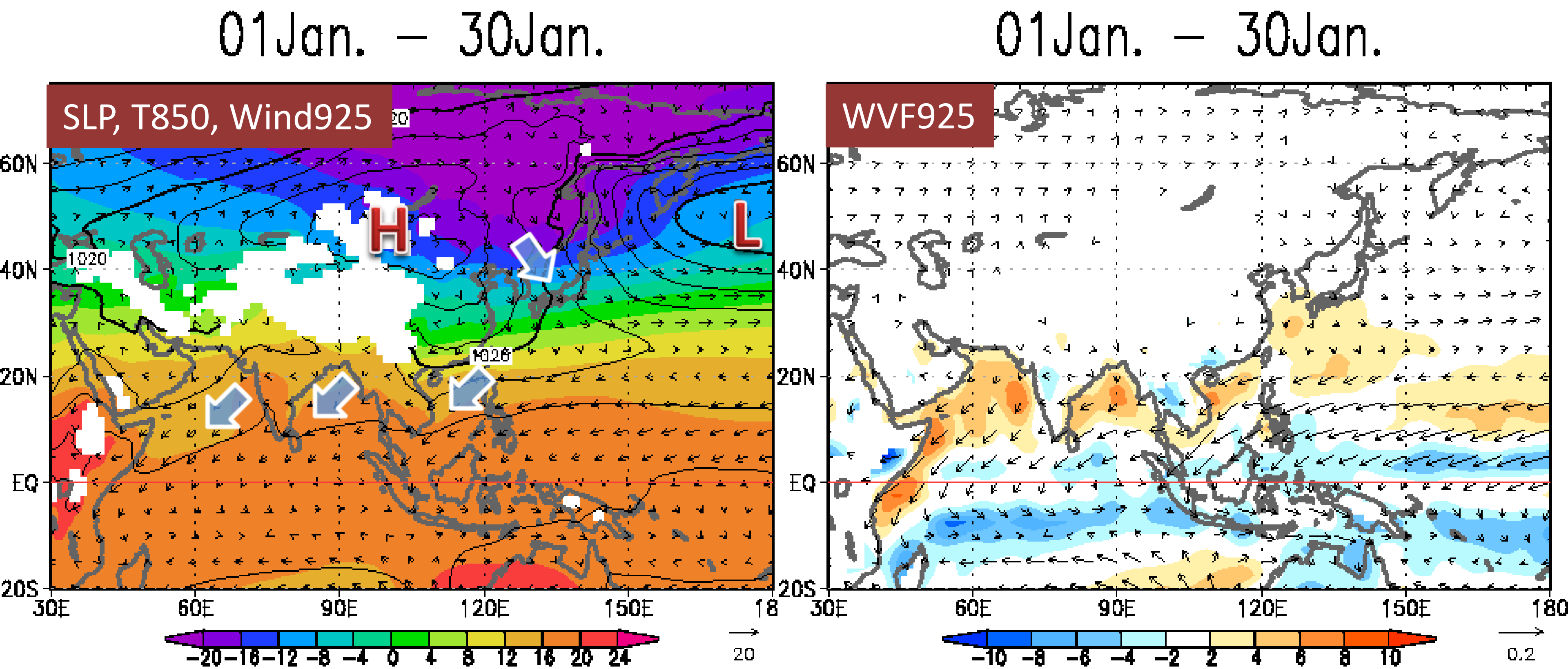
<u>Climatological normals of atmospheric circulation and convection (January)</u>

Contours: 200-hPa (left) and 850-hPa (right) stream function

Shading: OLR

Base period for normal: 1981 – 2010

Winter monsoon circulation (2)



<u>Climatological normals of atmospheric circulation (January)</u>

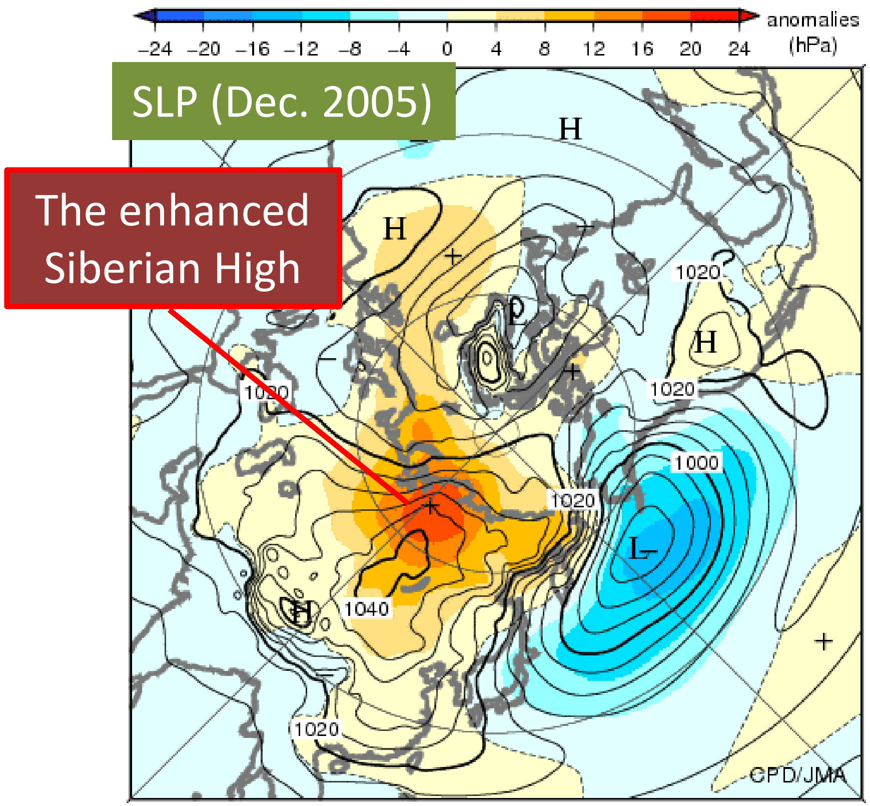
Left: Sea level pressure (contour), 850-hPa temperature (shading) and 925-hPa wind vectors

Right: 925-hPa water vapor flux (vector) and its divergence/convergence (shading)

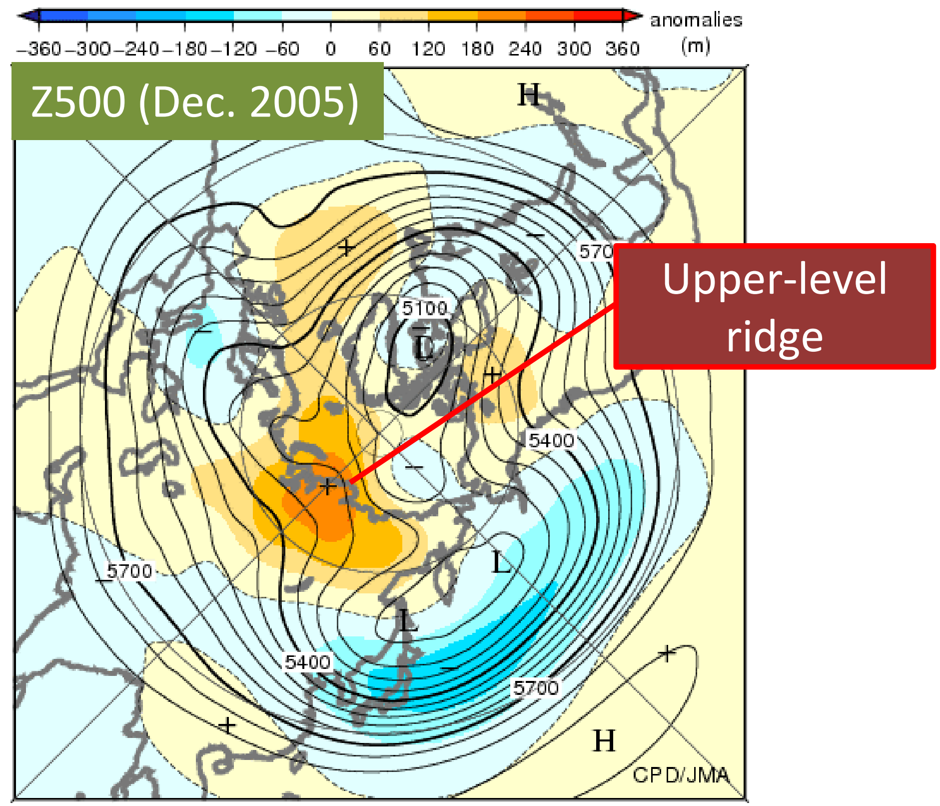
Base period for normal: 1981 – 2010

Siberian High

- The Siberian High governs the winter monsoon in eastern Asia.
- The amplification of the surface high is associated with formation of a blocking ridge in the upper troposphere (Takaya and Nakamura 2005a; 2005b).



Monthly mean sea level pressure and anomaly in the Northern Hemisphere (Dec.2005)
The contours show sea level pressure at intervals of 4 hPa.
The shading indicates sea level pressure anomalies.
Anomalies are deviations from the 1981–2010 average.

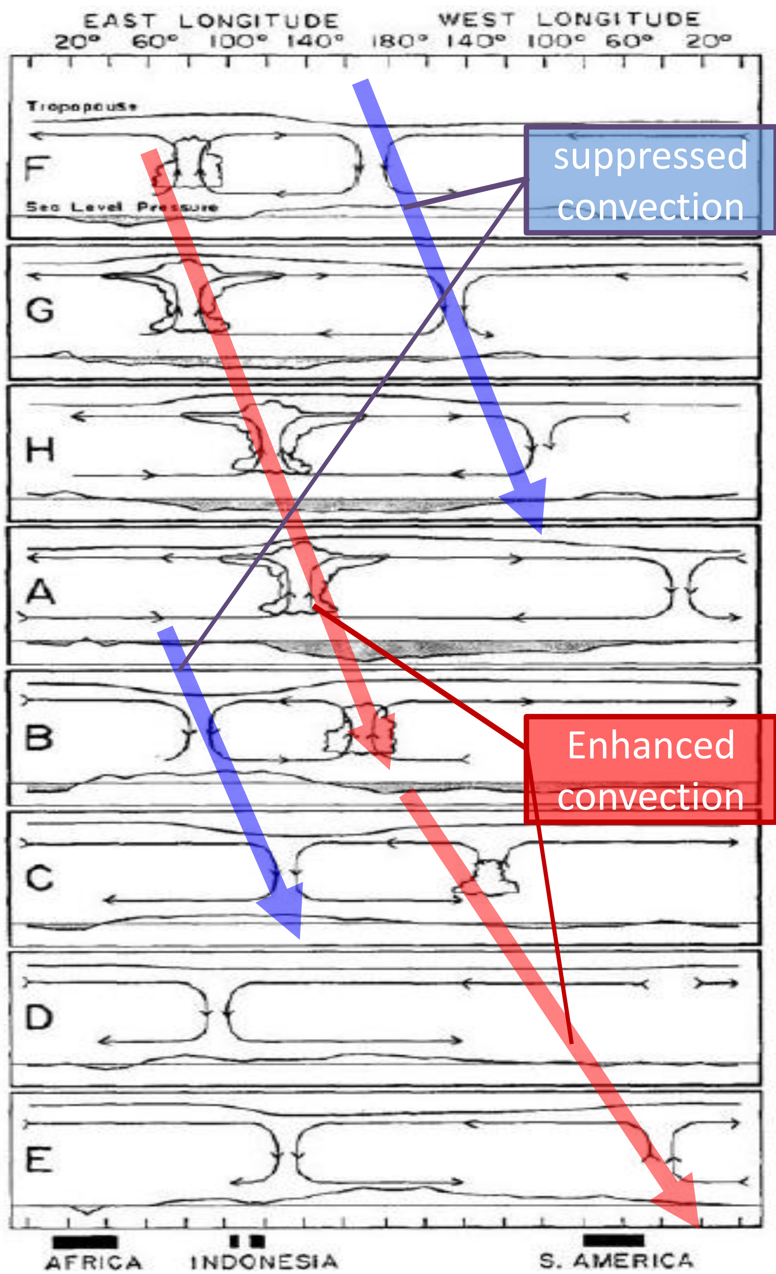


Monthly mean 500 hPa height and anomaly in the Northern Hemisphere (Dec.2005)
The contours show height at intervals of 60 m.
The shading indicates height anomalies.
Anomalies are deviations from the 1981–2010 average.

General features of MJO

MJO:

- Is a major intraseasonal oscillation in the tropics,
- Propagates eastward along the equator with periods of 30 – 60 days,
- Is a large-scale coupled pattern between deep convection and atmospheric circulation,
- Has a clearer signal in convection over the Indian Ocean and the western Pacific than the other tropical regions.



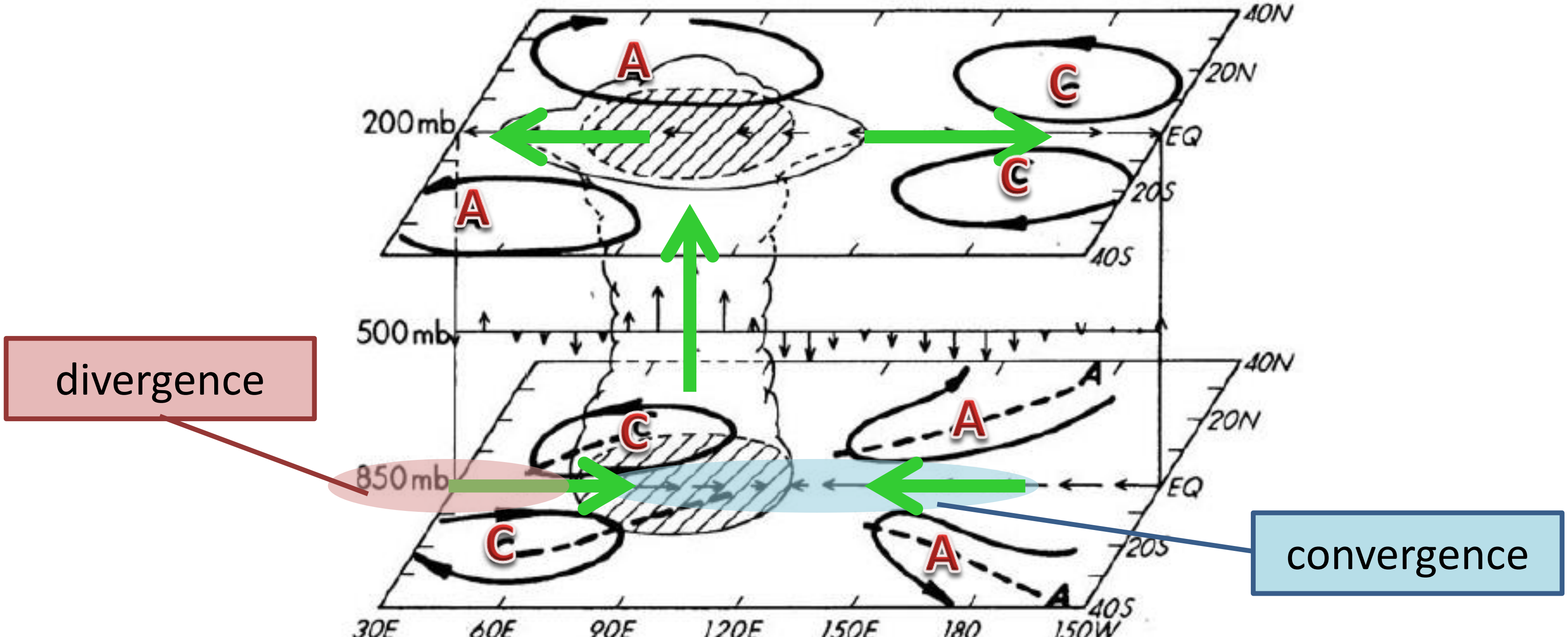
Schematic diagram of MJO

Time increasing downward

(Madden and Julian 1972)

Dynamical structure of MJO

- MJO has characteristics of both the equatorial Kelvin wave and the equatorial Rossby wave.
- The 3D-structure of MJO resembles atmospheric circulation anomalies responding to convective heating (Matsuno-Gill pattern)

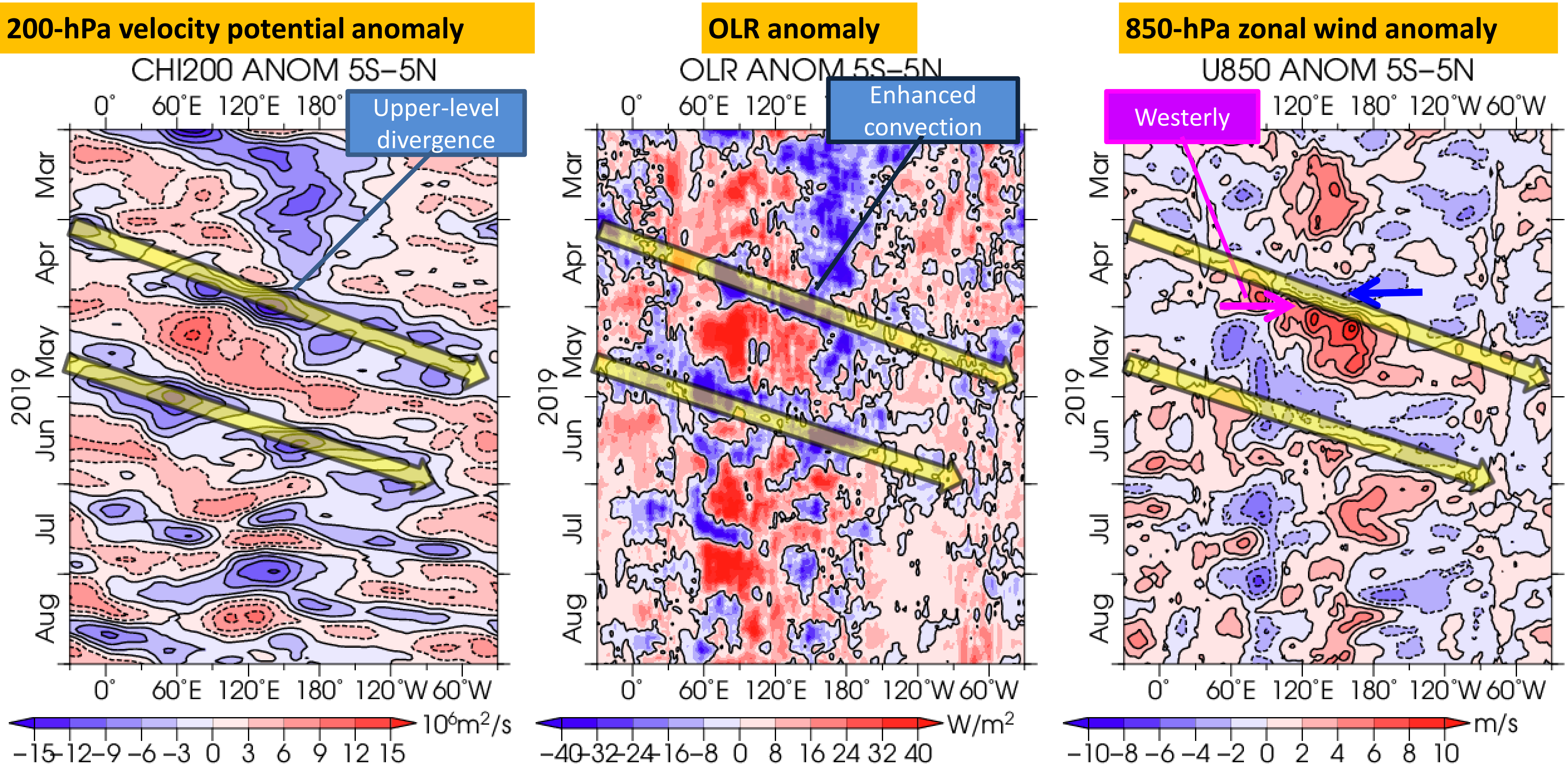


<u>Schematic depiction of large-scale wind structure of MJO (Indian Ocean)</u>

The cloud symbol indicates the convective center. Arrows represent anomalous winds at 850 and 200 hPa and the vertical motions at 500 hPa. “A” and “C” mark the anticyclonic and cyclonic circulation centers, respectively. (Rui and Wang 1990)

Analysis of MJO

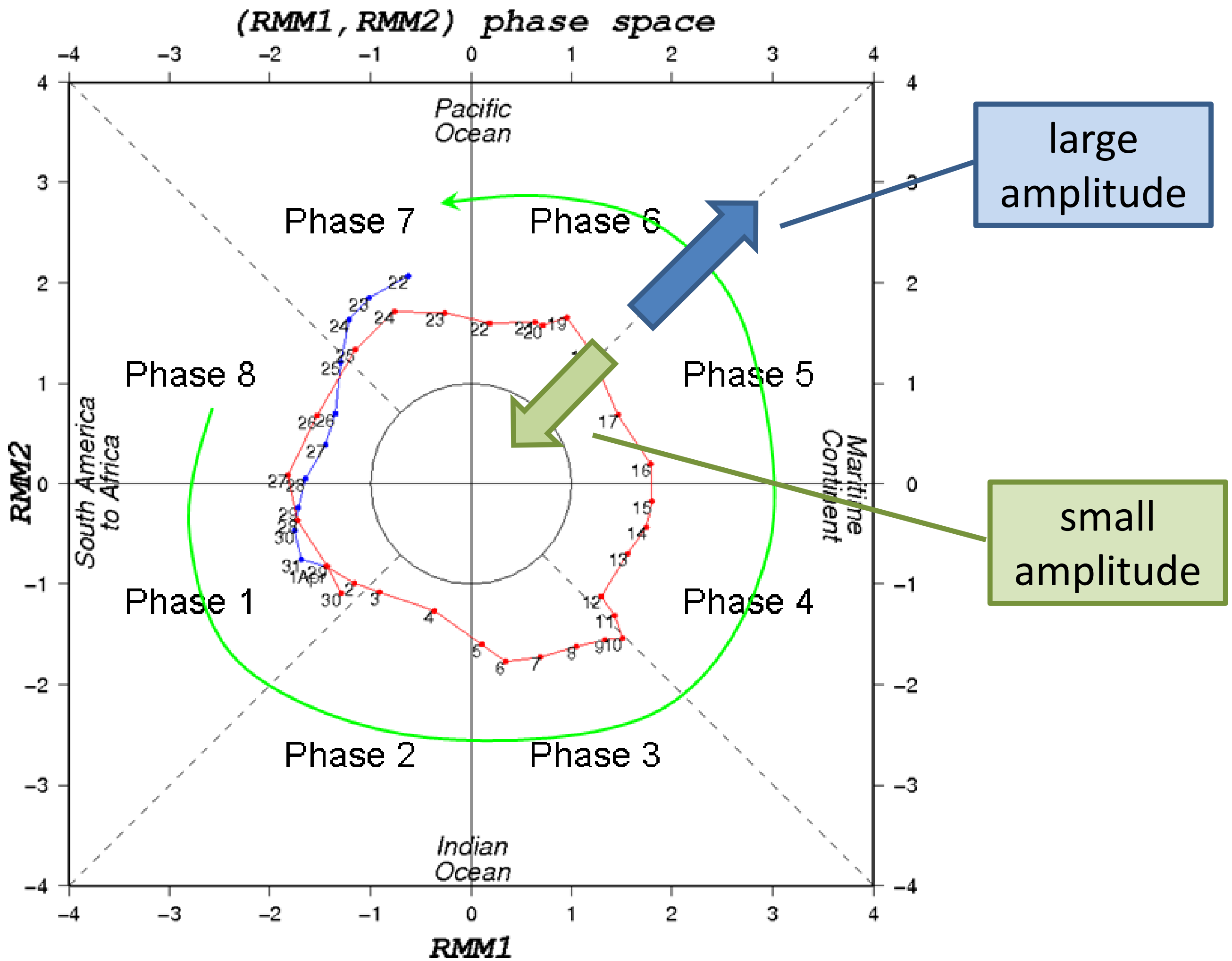
It is able to identify MJO using time-longitude cross sections of upper-level velocity potential, OLR, and lower-level zonal wind.



Time-longitude cross sections of 7-day running mean values of 200-hPa velocity potential anomaly (left), OLR anomaly (center) and 850-hPa zonal wind anomaly (right) around the equator (5S-5N), from March 2019 to August 2019.

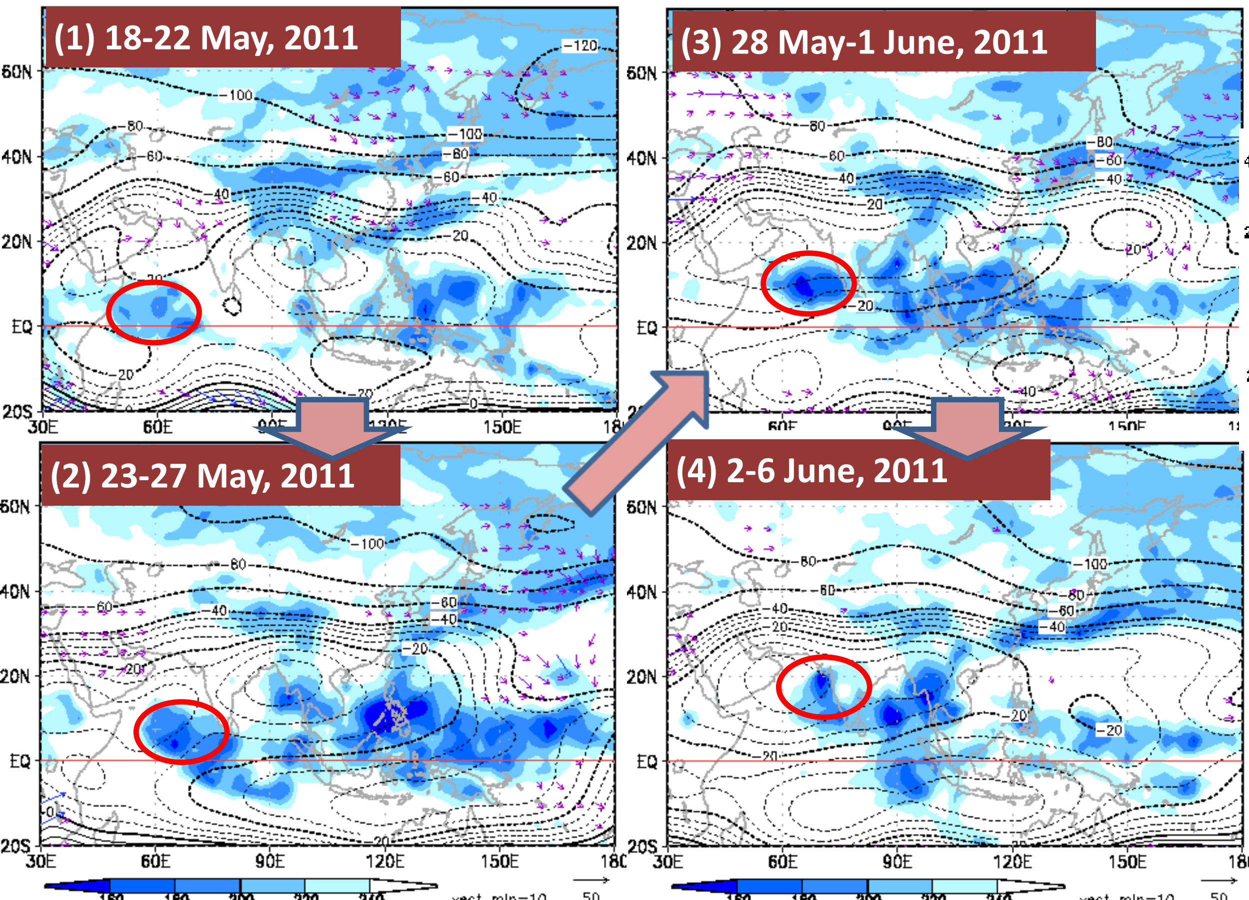
MJO Index

- Wheeler and Hendon（2004）defined MJO indices based on the EOF of OLR, U200 and U850 data in which seasonal, interannual and ENSO variations are subtracted in advance.
- In the phase space, each phase indicates the active phase of the MJO propagation.

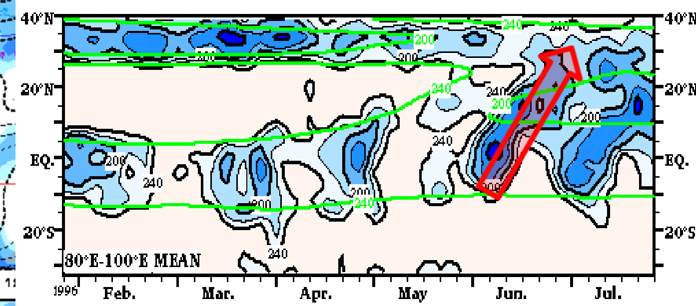


Boreal summer intraseasonal oscillation (BSISO)

- Northward propagation of active/inactive convection areas are seen over the northern Indian Ocean and the western North Pacific, associated with MJO.
- This affects the monsoon onset and active/break events (intraseasonal oscillation).



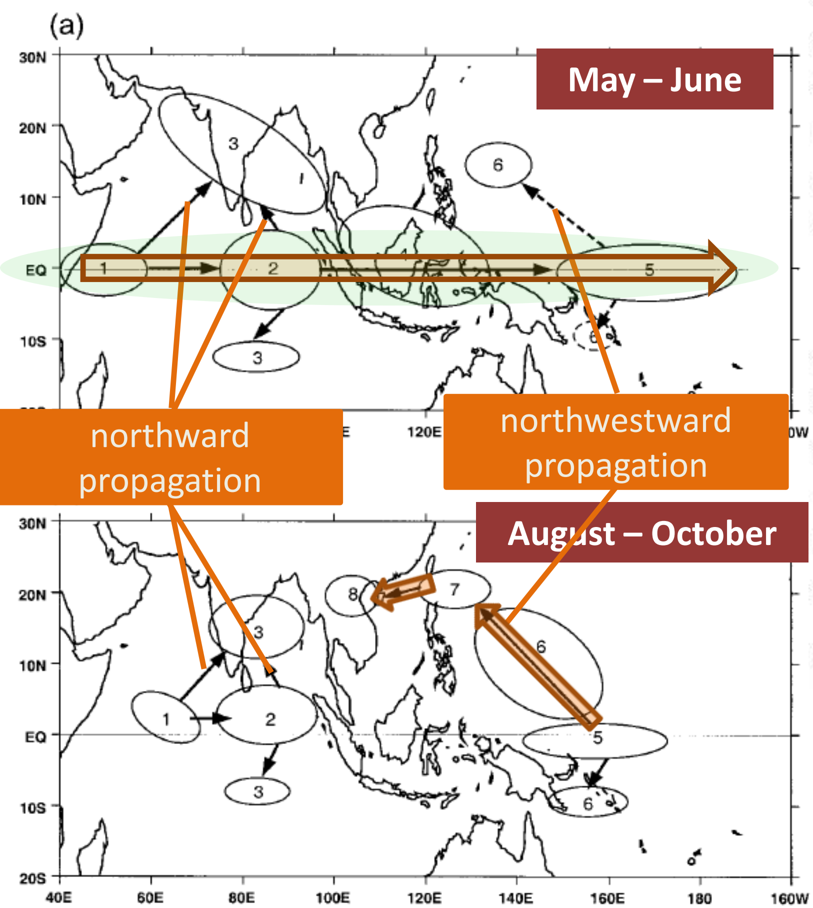
Five-day mean 200-hPa stream function and OLR



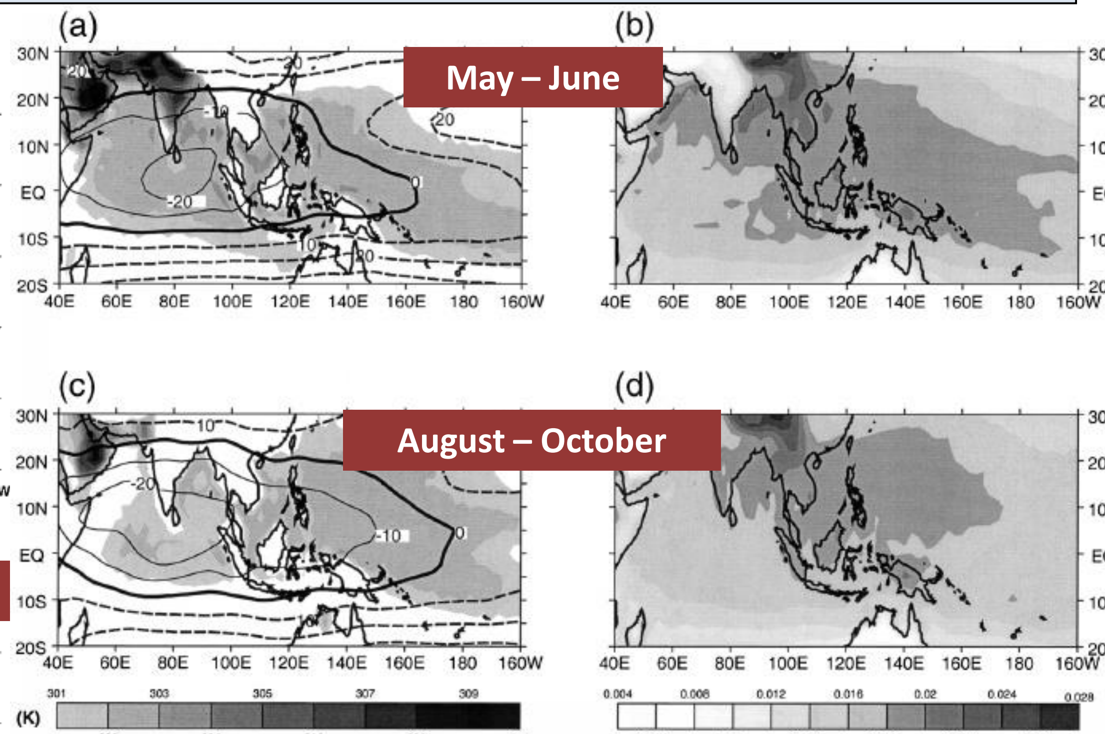
Latitude-time cross section of seven-day running mean OLR averaged 80˚E – 100˚E (around Indian sub-continent)

Life cycle of BSISO

The characteristics of BSISO are different in early and late boreal summer, due to differences in climatological conditions.



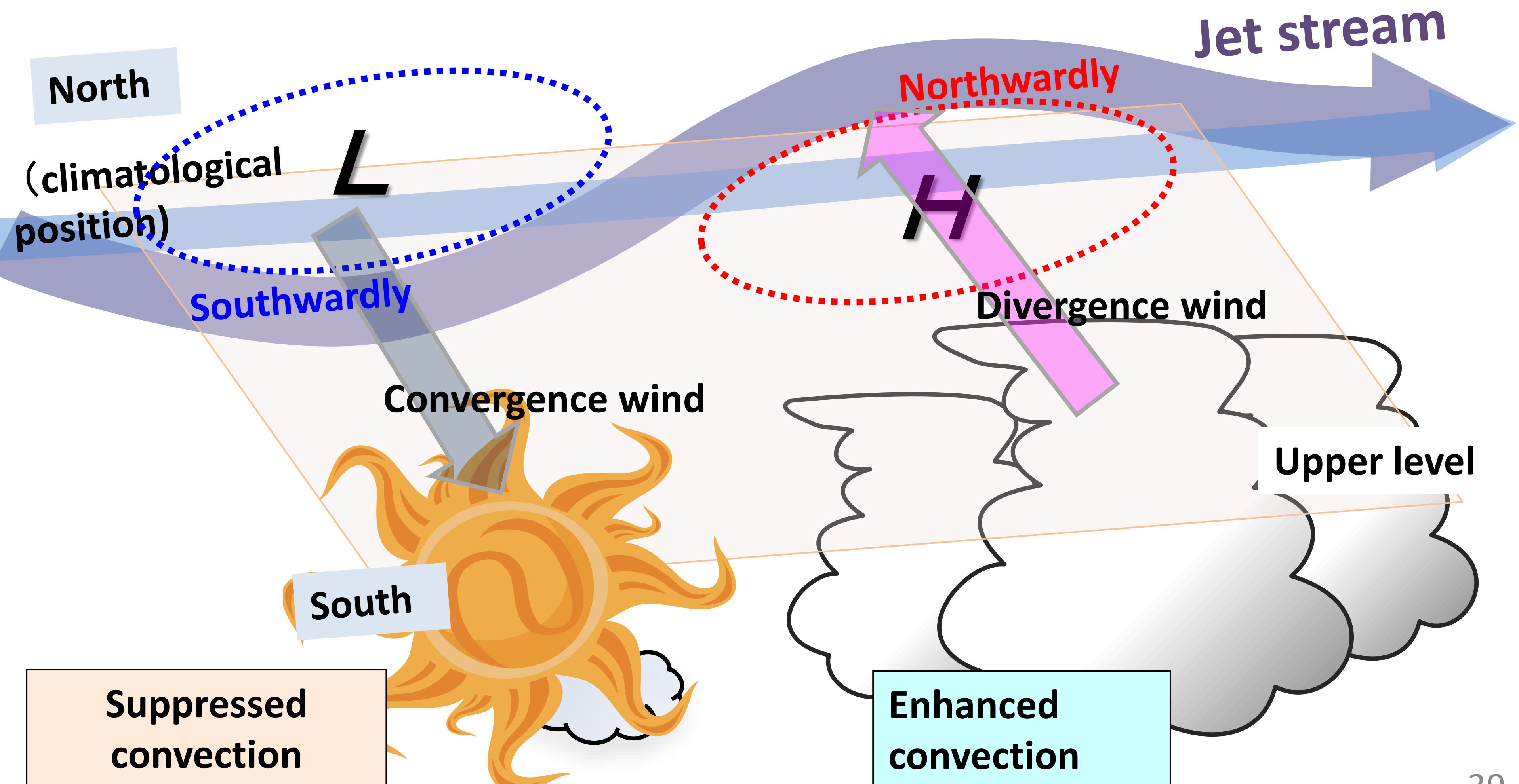
BSISO convection life cycle
(Kemball-Cook and Wang 2001)



Climatological condition in May – June (top) and August – October (bottom)
In left panels, contours indicate vertical shear of zonal wind (U200 – U850), and shading shows surface temperature.
In right panels, shading shows specific humidity at 1000 hPa.
(Kemball-Cook and Wang 2001)

Meanderings of jet stream by anomalous convections

Shifted **northwardly** (north side of enhanced convections)
Shifted **southwardly** (north side of suppressed convections)

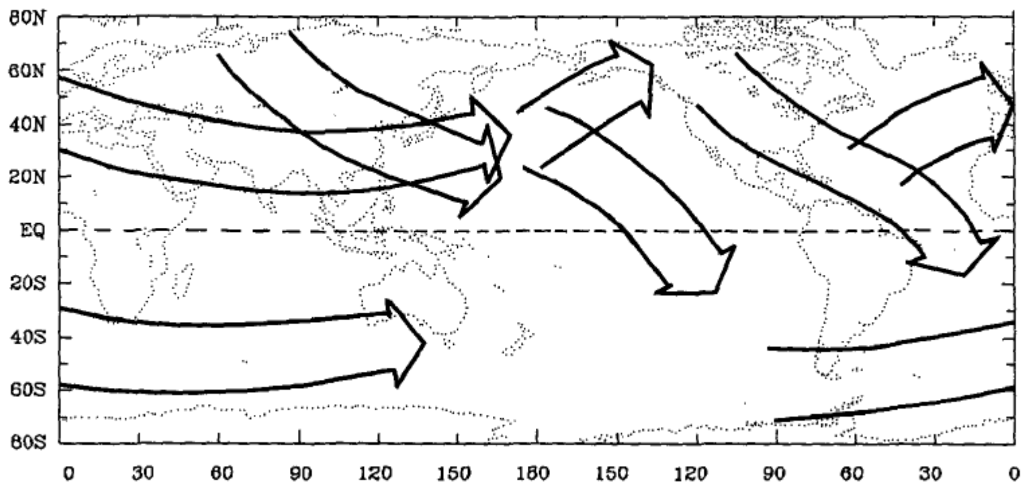


Quasi-stationary Rossby Wave

- Meandering of the westerly wind often persists for more than a week due to (quasi-)stationary Rossby wave.
- Stationary Rossby wave often causes extreme weather (ex. hot/cold spell, drought…)
- The wave energy propagates eastward often along the sub-tropical and polar front jet streams (teleconnection).

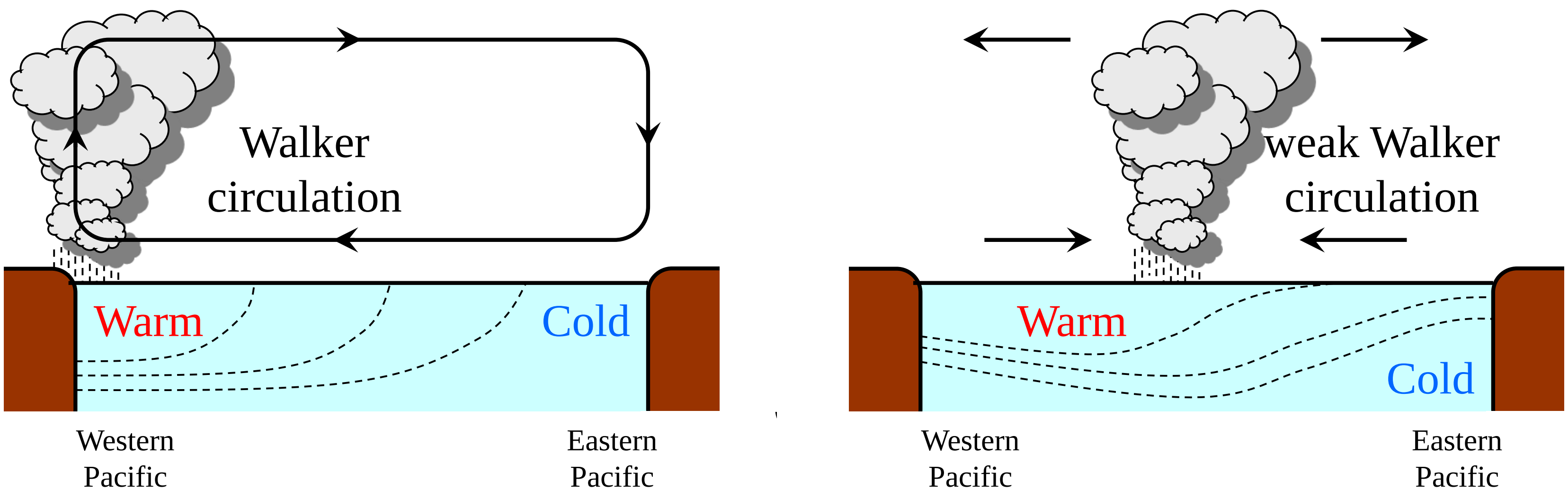
Typical path of Rossby wave energy propagation

(Hsu and Lin, 1992)



General features of ENSO

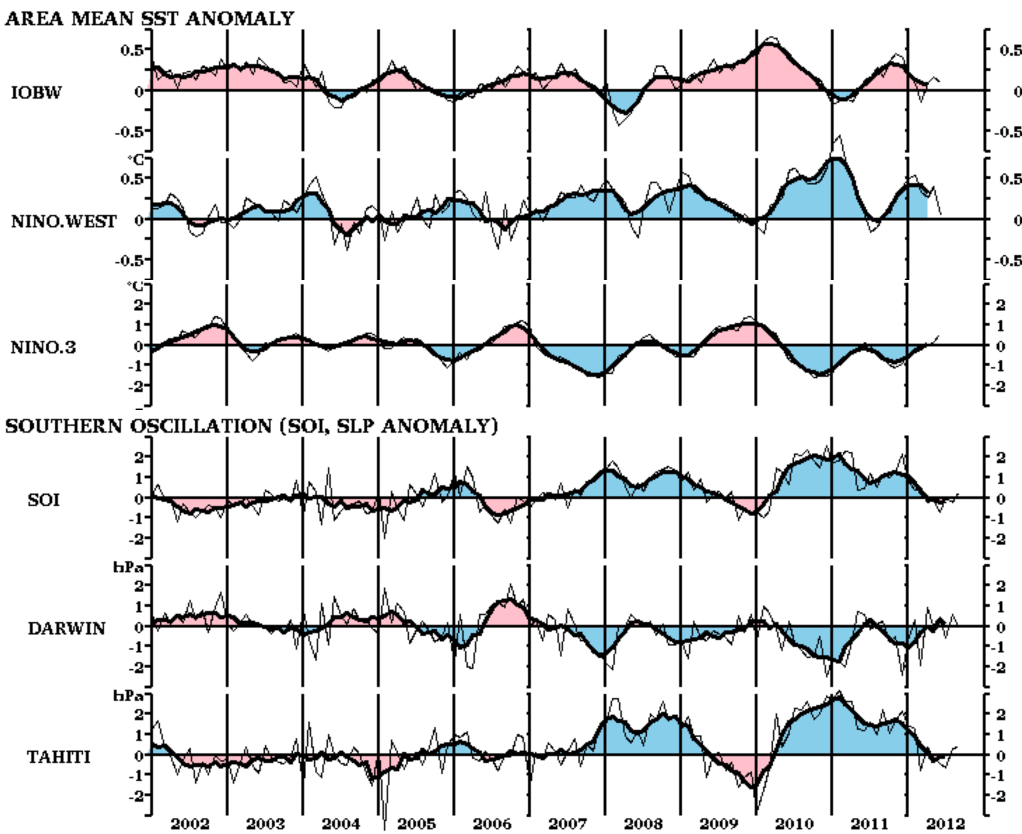
- El Niño (La Niña): A significant increase (decrease) in SST over the eastern and central equatorial Pacific that occurs at irregular intervals, generally ranging between two and seven years.
- Southern Oscillation (SO): Planetary-scale “seesaw” in sea level pressure, with one pole in the eastern Pacific and the other in the western Pacific–Indian Ocean region.
- The SO is recognized to be primarily a response to basin-scale SST variations in the equatorial Pacific arising from coupled ocean–atmosphere interactions, the opposite extremes of which are the El Niño and La Niña.

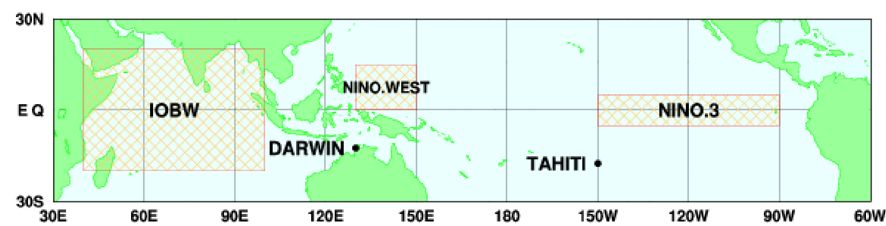


Normal (or La Niña) El Niño

ENSO monitoring indices

- JMA defines El Niño/La Niña events as a phenomenon in which the five-month running-mean values of monthly SST deviations from the sliding 30-year mean for the El Niño monitoring region (NINO.3: 5˚S – 5˚N, 150˚W – 90˚W) stay at +0.5˚C or above/-0.5˚C or below for six consecutive months or longer.

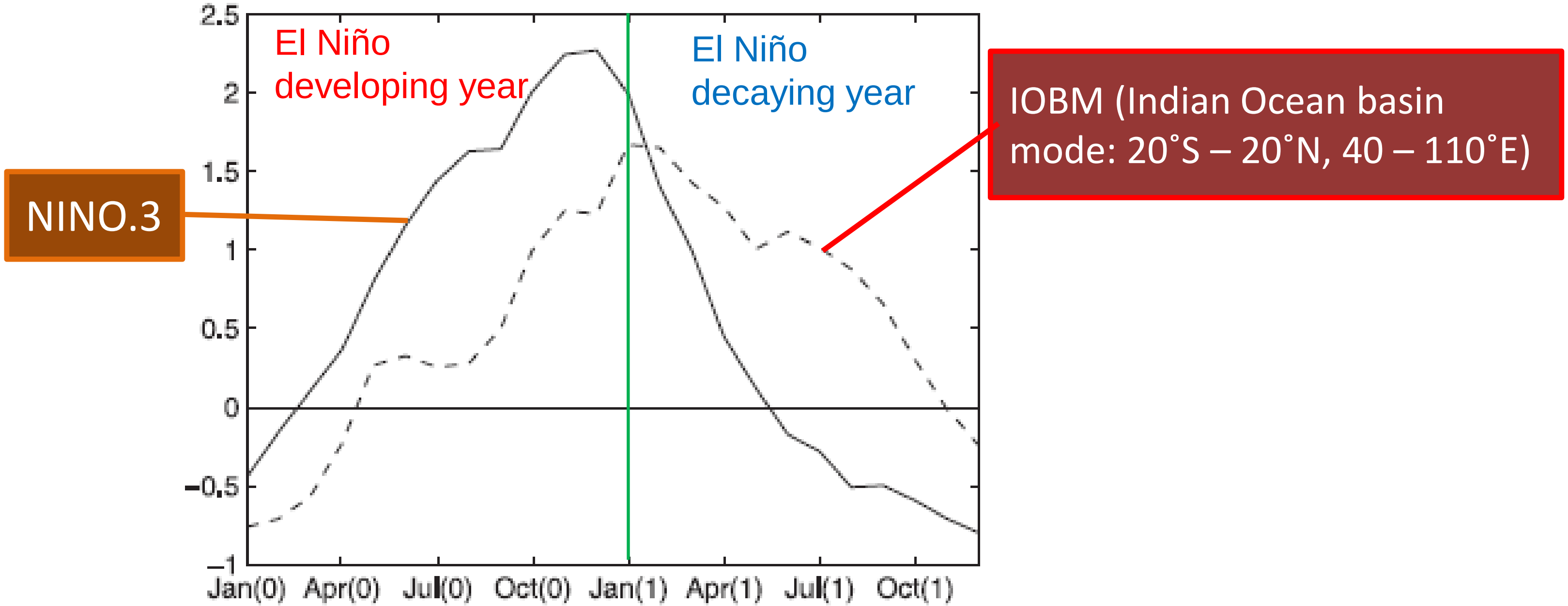




ENSO-related monitoring indices

Indian Ocean SSTs and ENSO

Following an El Niño event, a basin-wide warming takes place over the tropical Indian Ocean, peaks in late boreal winter and early spring, and persists through boreal summer (e.g., Yang et al., 2007).



<u>Evolution of a composite El Niño event</u>

The NINO.3 (solid) and IOBM (dashed) indices normalized by their respective annual-mean standard deviations. Numerals “0” and “1” denote years during which El Niño develops and decays, respectively. (Yang et al. 2007)

Outline

1. Introduction to climate analysis information
2. Climate system monitoring and analysis
    - Basic knowledge
    - Activities at JMA
3. Example of climate analysis information

Monitoring and analysis for the climate system

- JMA monitors the global atmospheric circulation, convection, ocean conditions and snow/ice coverage.
- JMA issues monthly and seasonal bulletins focusing on the monthly and seasonal highlights of the monitoring results.

HOME > Climate System Monitoring > Monthly Highlights on the Climate System

Monthly Highlights on the Climate System

'Monthly Highlights on the Climate System' has been issued in PDF format since March 2007 as a monthly bulletin focusing on the monthly highlights of the monitoring results.

Highlights in September 2019

- Monthly mean temperatures were significantly above normal from northern to w
- Monthly mean temperatures were extremely high from eastern Japan to Mongoli Arabia, from the western part of Western Africa to the western part of Middle Afric from the eastern USA to southern Mexico, and in and around central Brazil.
- In the equatorial Pacific, remarkably positive SST anomalies were observed in th
- Convective activity was enhanced from the southern part of the Middle East to th the western equatorial Indian Ocean, the seas northeast of the Philippines, and th eastern Pacific, and was suppressed from the southeastern tropical Indian Ocean t
- In the 500-hPa height field, positive anomalies were seen over the northern pola Asia, the seas south of Alaska, the eastern USA, and the seas west of Europe, and northeast of the Caspian Sea and over Eastern Siberia.

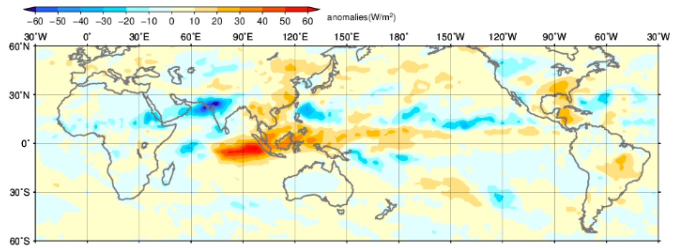


Fig. 6 Monthly mean Outgoing Longwave Radiation (OLR) anomaly (September 2019)

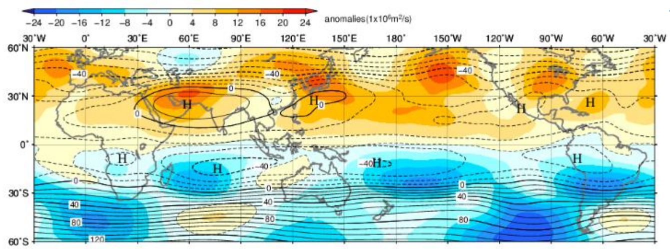


Fig. 8 Monthly mean 200-hPa stream function and anomaly (September 2019)
The contour interval is 10×10^6 m^2/s. The base period for the normal is 1981-2010.

Full version (PDF)

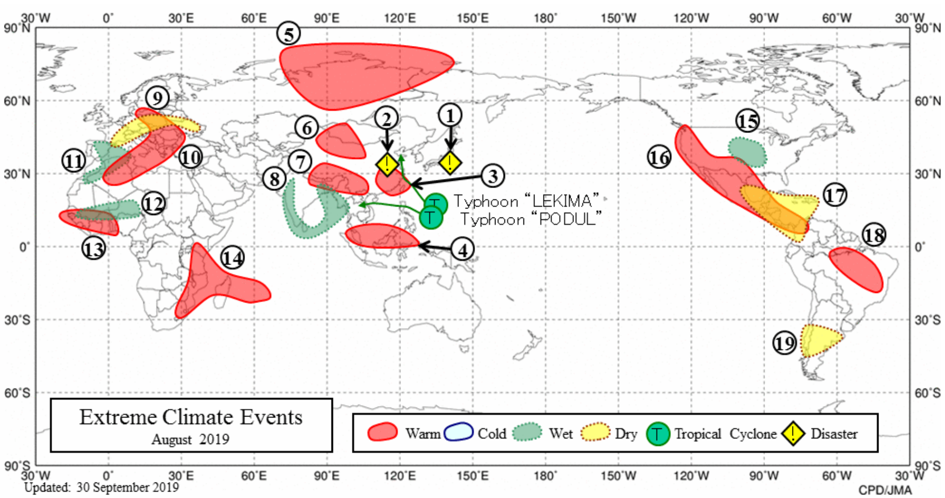
- Monthly Highlights on the Climate System (September 2019)
- Back Number

Back Number (PDF)

Monthly Highlights: https://ds.data.jma.go.jp/tcc/tcc/products/clisys/highlights/index.html
Seasonal Highlights: https://ds.data.jma.go.jp/tcc/tcc/products/clisys/season_highlights/index.html

Monitoring and analysis for extreme climate event

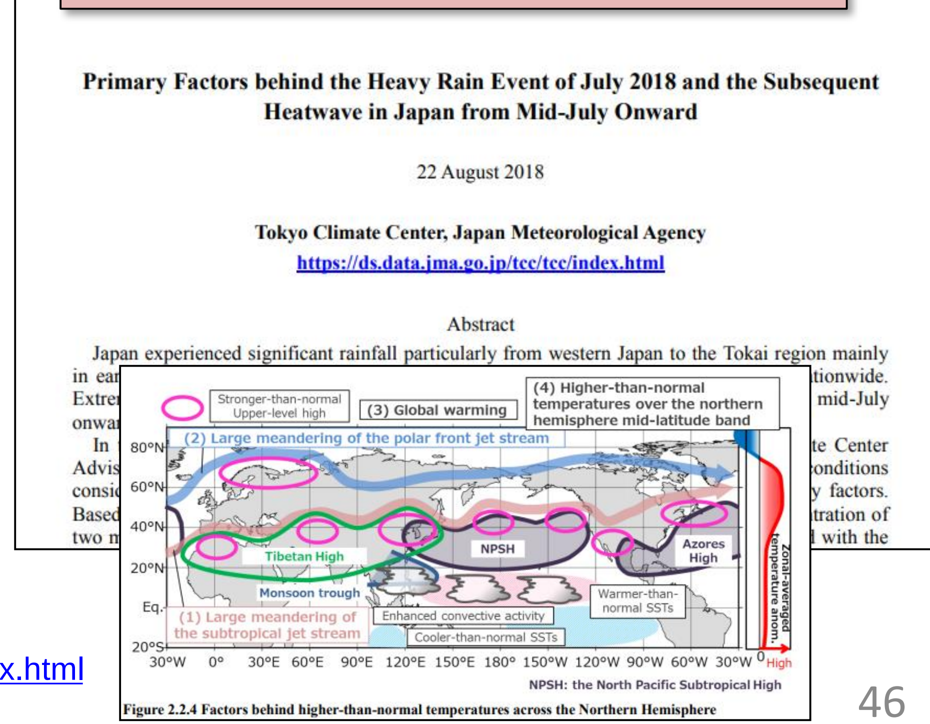
- JMA provides weekly, monthly, seasonal and annual reports for extreme climate events.
- When an extreme climate event that affects socio-economic activities occurs, JMA issues the climate information.



Distribution of Extreme Climate Events (August 2019)

https://ds.data.jma.go.jp/gmd/tcc/tcc/products/climate/monthly/index.html

Press release "Primary Factors behind the Heavy Rain Event of July 2018 and the Subsequent Heatwave in Japan from Mid-July Onward"（22 August 2018）



Primary Factors behind the Heavy Rain Event of July 2018 and the Subsequent Heatwave in Japan from Mid-July Onward

22 August 2018

Tokyo Climate Center, Japan Meteorological Agency

https://ds.data.jma.go.jp/tcc/tcc/index.html

Abstract

Japan experienced significant rainfall particularly from western Japan to the Tokai region mainly in ear… …tionwide. Extre… …mid-July onwa…

In … …te Center Advis… …onditions consi… …y factors. Based… …tration of two n… …l with the

Figure 2.2.4 Factors behind higher-than-normal temperatures across the Northern Hemisphere

https://ds.data.jma.go.jp/tcc/tcc/products/clisys/reports/index.html

Advisory Panel on Extreme Climate Events

When an extreme climate event has occurred or is expected

JMA

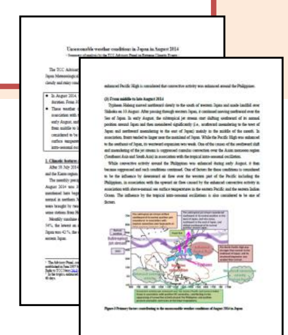
Extraordinary meeting

Analysis of the event

at the JMA headquarters / on-line meeting

Research Community

Timely statement on causes of the extreme climate event



https://ds.data.jma.go.jp/tcc/tcc/news/index.html

Advisory Panel on Extreme Climate Events

- **Background**

When an extreme climate event occurs,

- JMA is expected to provide proper information on current status, cause, and outlook.
- Devising more effective ways to bring research results to operational activities are important.

Advisory Panel was established in 2007.

Missions

- To investigate extreme climate events based on a climatological approach
- To advise and assist JMA in issuing statements on such events
- To recommend related application of the latest findings

Advisory Panel on Extreme Climate Events

At a normal time

JMA

- Integrated environment for climate analysis with various data and analysis tools
- Operational monitoring information on climate system

- Scientific comments on climate monitoring
- Suggestion on improvement of analysis

Research Comunity

JMA routinely shares information on the current conditions of the climate system and discusses climatic anomalies with the Panel using a dedicated website and e-mail communication

Monthly climate diagnostic meeting （WEB meeting）

Weekly comment

Outline

1. Introduction to climate analysis information
2. Climate system monitoring and analysis
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3. Example of climate analysis information

Structure of the information

1: Surface climate conditions

Assess surface climate conditions, and if possible related impacts referring to official information source.

2: Characteristic atmospheric circulation

Identify atmospheric circulation directly contributing to the targeted surface climate conditions.

3: Factor analysis (if possible)

Investigate the possible factors associated with the identified atmospheric circulation directly contributing to the targeted surface climate conditions.

Example:

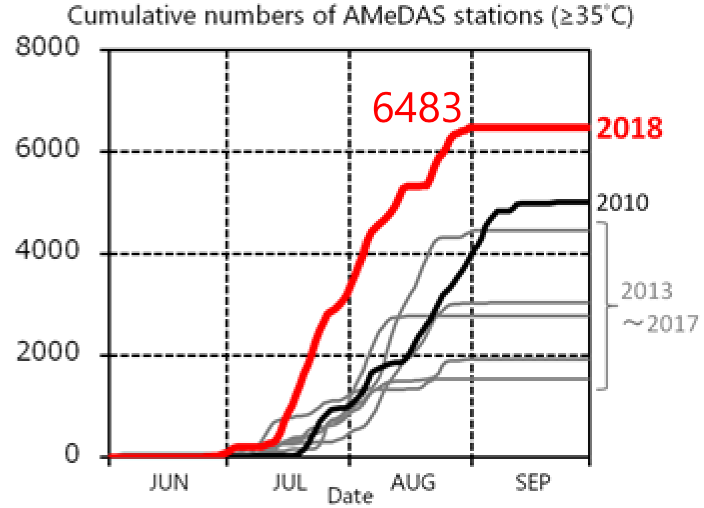
Heatwave in Japan in boreal summer 2018

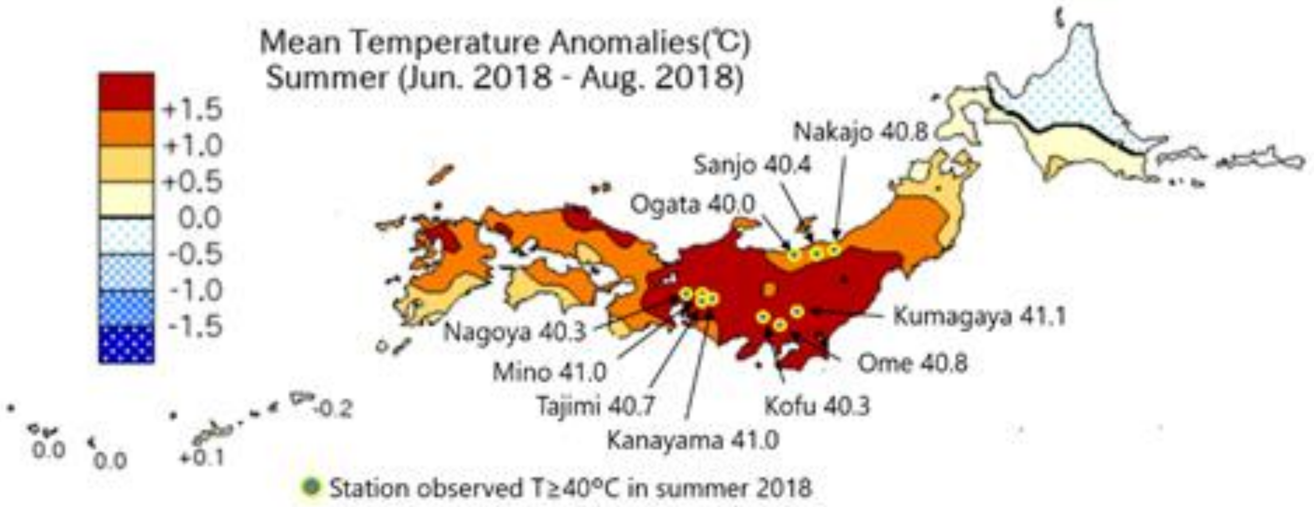
1. Surface climate conditions

Heatwave in Japan in boreal summer 2018

- The monthly mean temperature anomalies for July 2018 (+2.8°C) and JJA 2018 (+1.7°C) in eastern Japan were the highest on record for July and JJA since 1946, respectively.
- On 23rd July a new national record maximum temperature of 41.1°C was recorded at Kumagaya in Saitama Pref.
- Cumulative number with daily temperatures of 35°C or more from June to September was the highest since 1976.

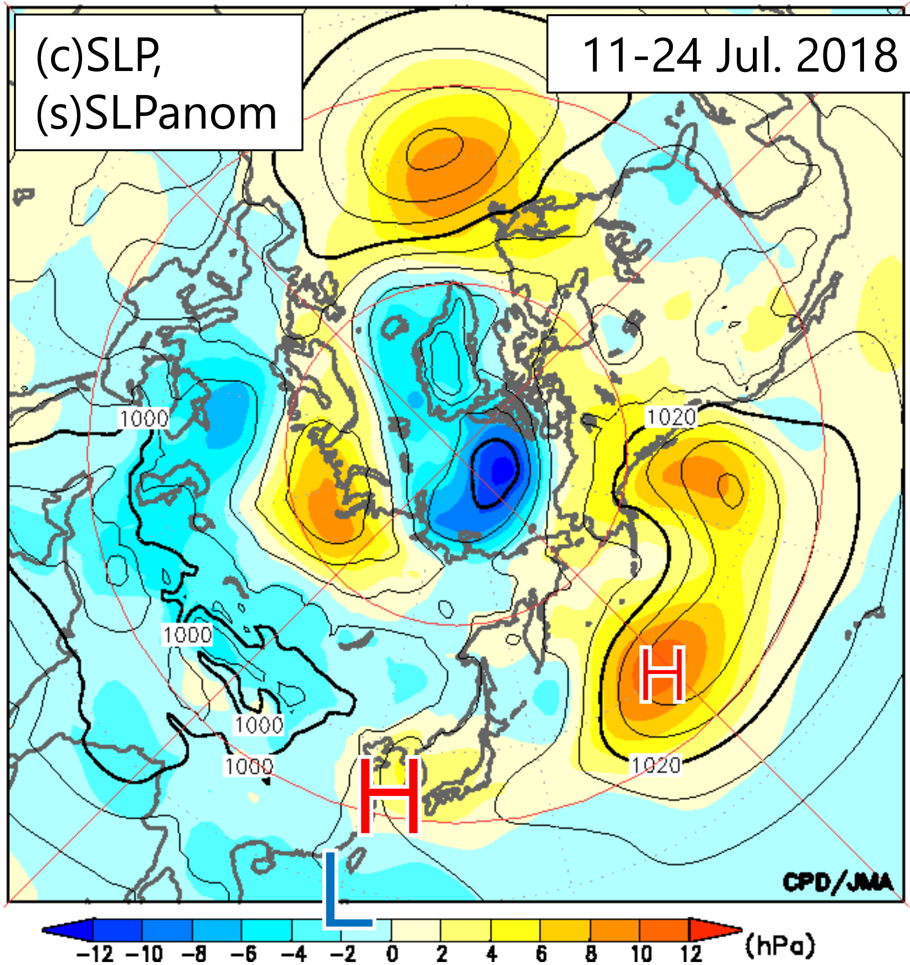
Cumulative No. of AMeDAS stations with daily maximum temperatures of 35°C or more (Jun.-Sep. (JJAS); 2010-2014)

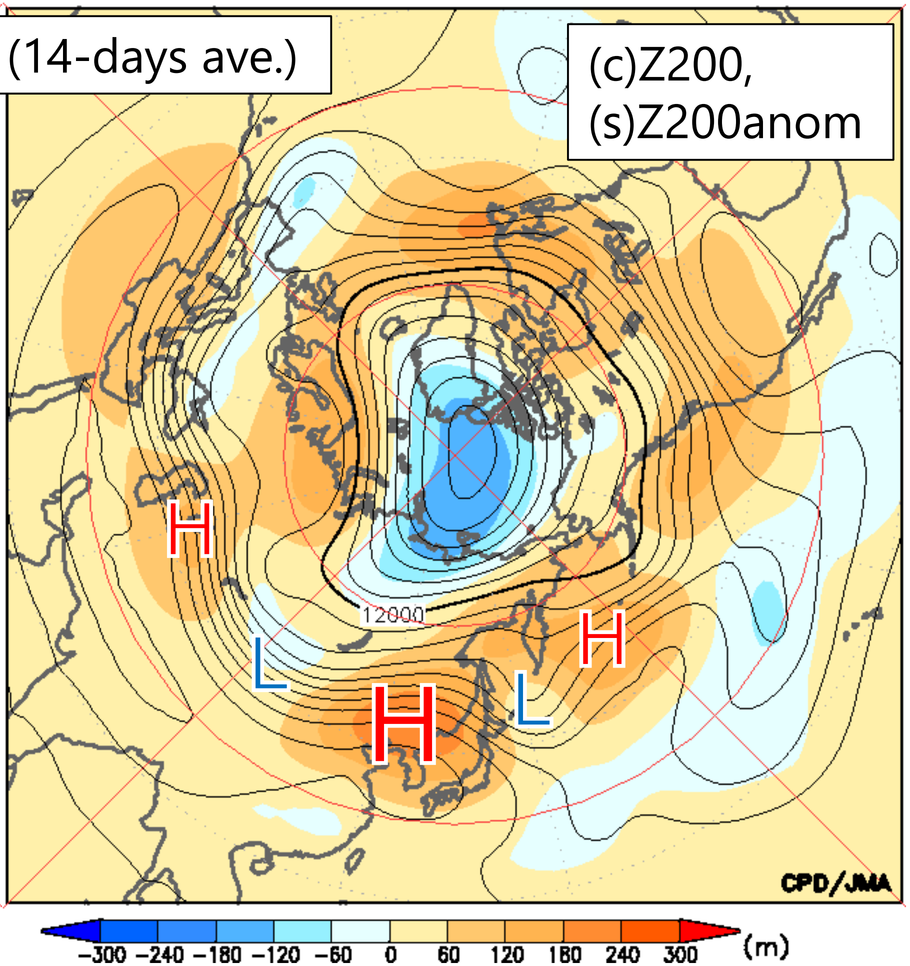




2. Atmospheric circulation

- Both the North Pacific Subtropical High and the Tibetan High expanded to the main islands of Japan and persisted.
- Surface temperatures in Japan increased, due mainly to high-pressure systems with warmer-than-normal air covering the islands, predominant sunny conditions and downward flow associated with the pressure systems, influenced by northward meandering of the subtropical jetstream in the vicinity of Japan.



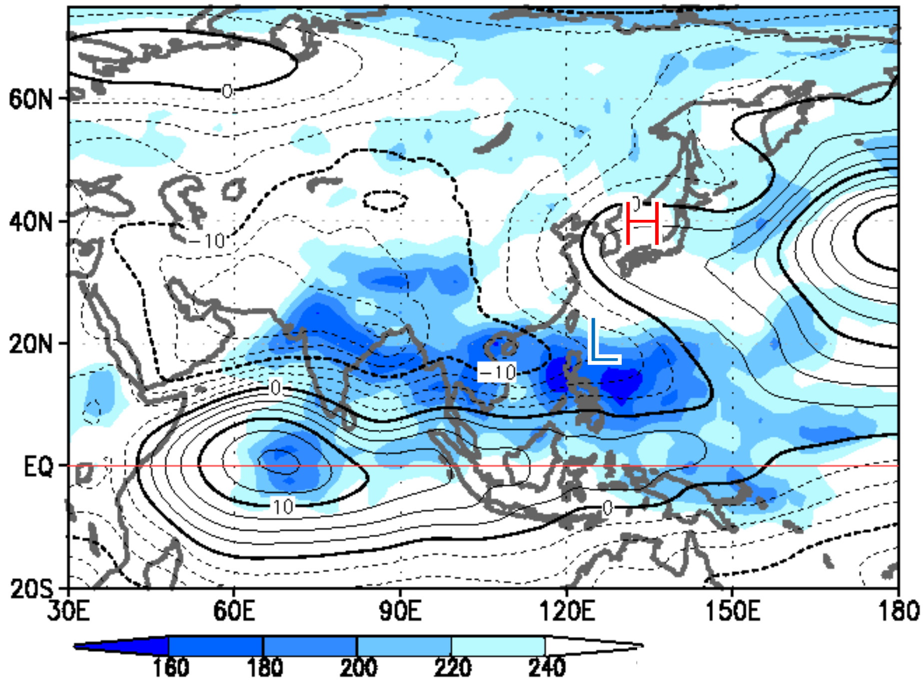


2. Atmospheric circulation (cont.)

- The expansion of the North Pacific Subtropical High in the vicinity of Japan was attributable to enhanced convective activity over and around the Philippines with stronger-than-normal large-scale lower-level cyclonic circulation over the area from Southeast Asia to the Philippines (the Pacific-Japan (PJ) pattern (Nitta 1987; Kosaka and Nakamura 2010)).

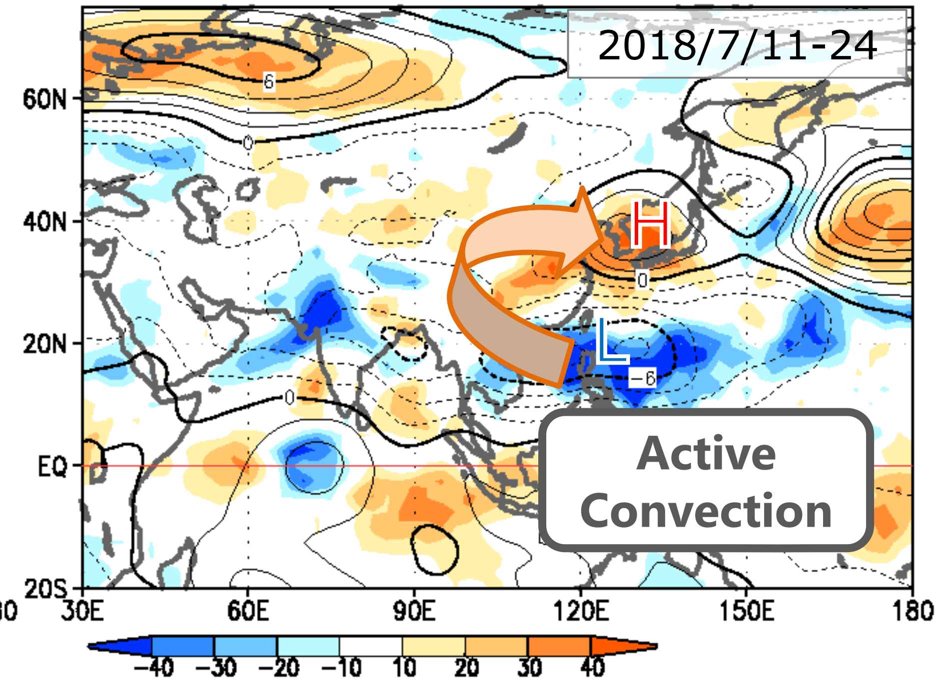
11-24 Jul. 2018(14-days ave.)

(c)PSI850 [$10^6 m^2/s$], (s)OLR [W/m^2]



<- Active convection

(c)PSI850anom [$10^6 m^2/s$], (s)OLRanom [W/m^2]



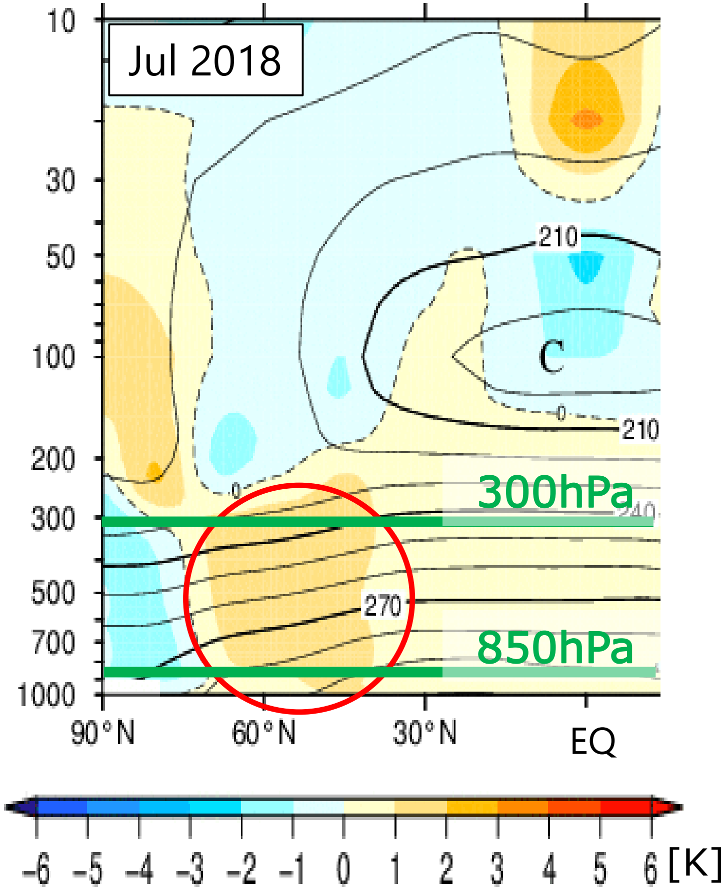
<- Active convection

Inactive -> convection

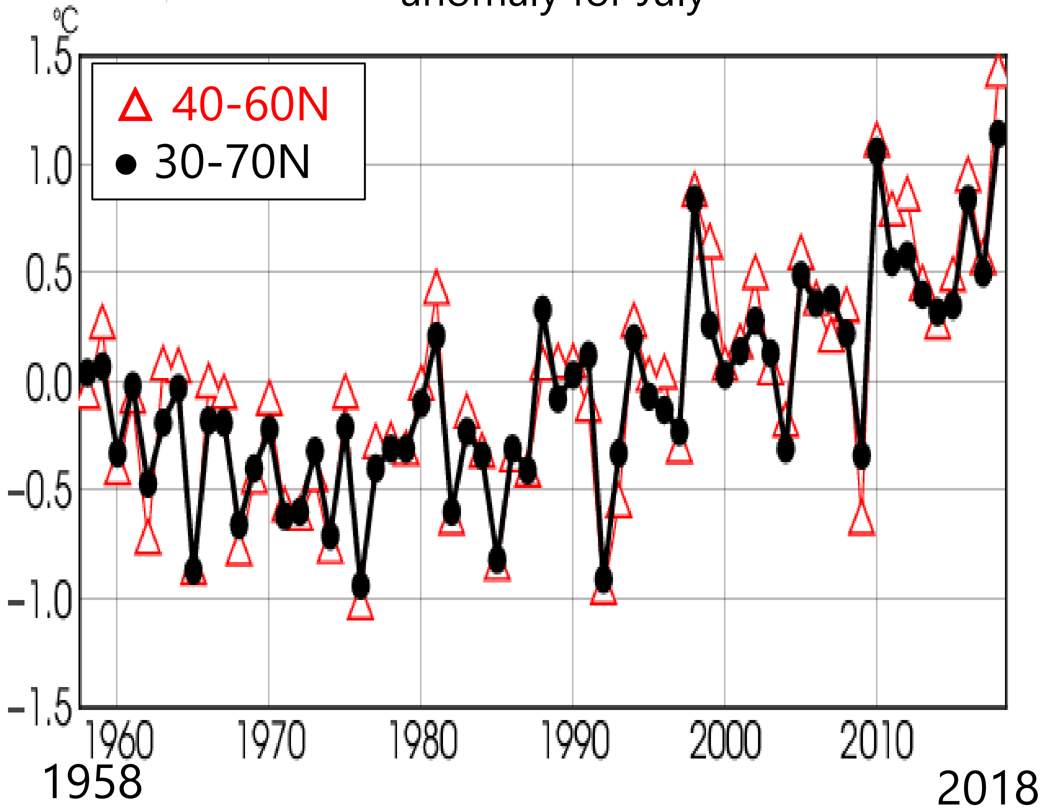
3. Factor analysis: High temperature in NH mid-latitude

Zonally averaged tropospheric air temperatures in the mid-latitudes of the Northern Hemisphere (NH; e.g., 40 – 60°N) had been high since boreal spring 2018, and the value for July 2018 was the highest for July since 1958.

(c) Zonal mean temperature [K],
(s) Zonal mean temperature anom. [K]



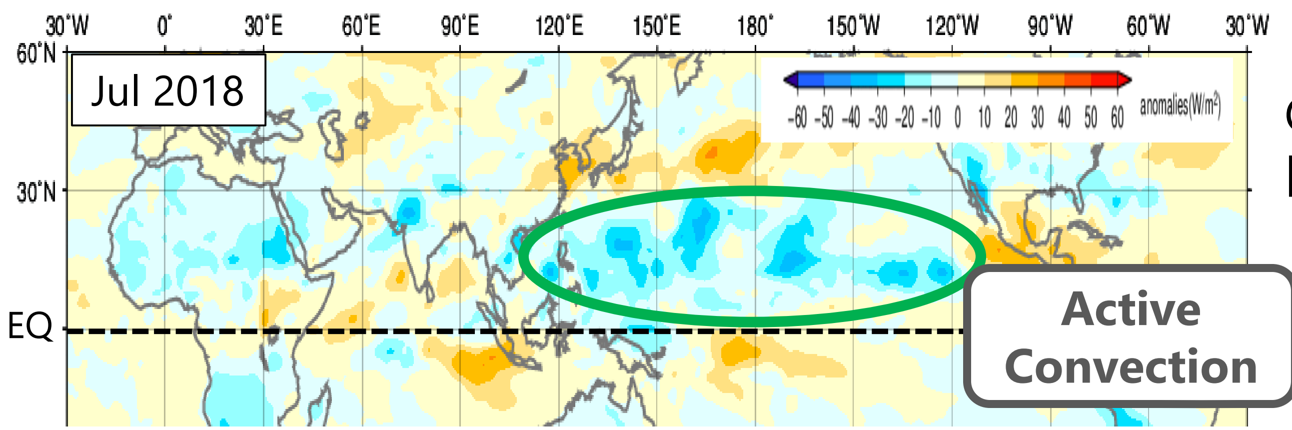
Zonal mean tropospheric temperature anomaly for July



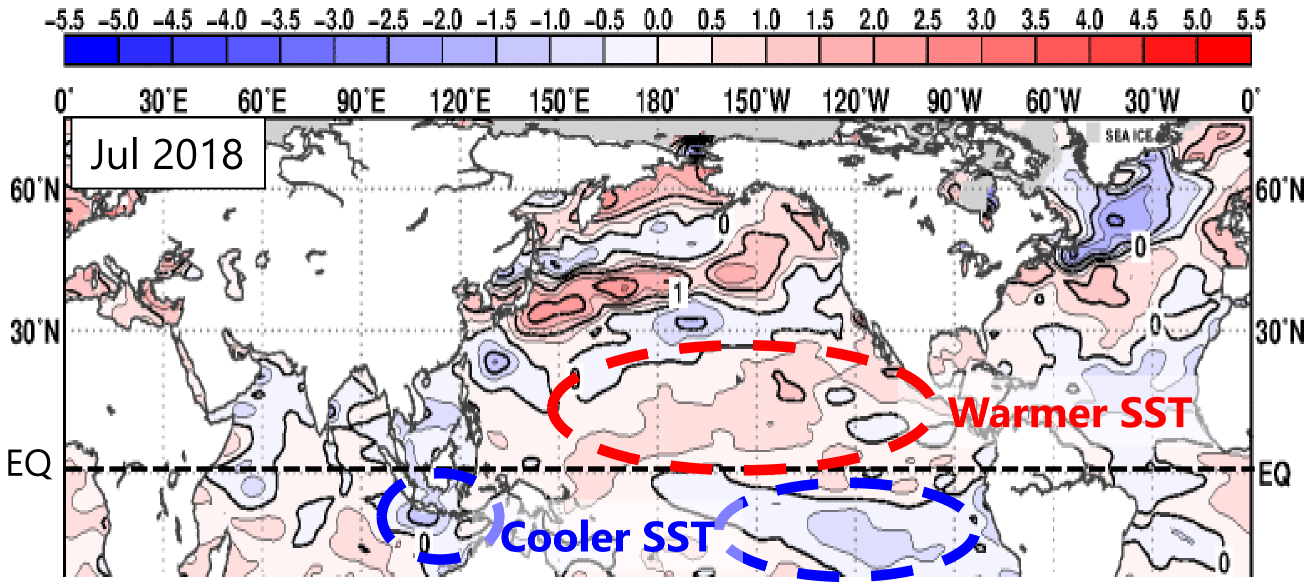
(Tropospheric temperature is estimated between 300hPa and 850hPa.)

3. Factor analysis: High temperature in NH mid-latitude (cont.)

This high temperature in the mid-latitudes of the NH was attributable to enhanced convective activity over a wide area of the NH in association with higher (lower)-than-normal SSTs over the tropics in the NH (SH).

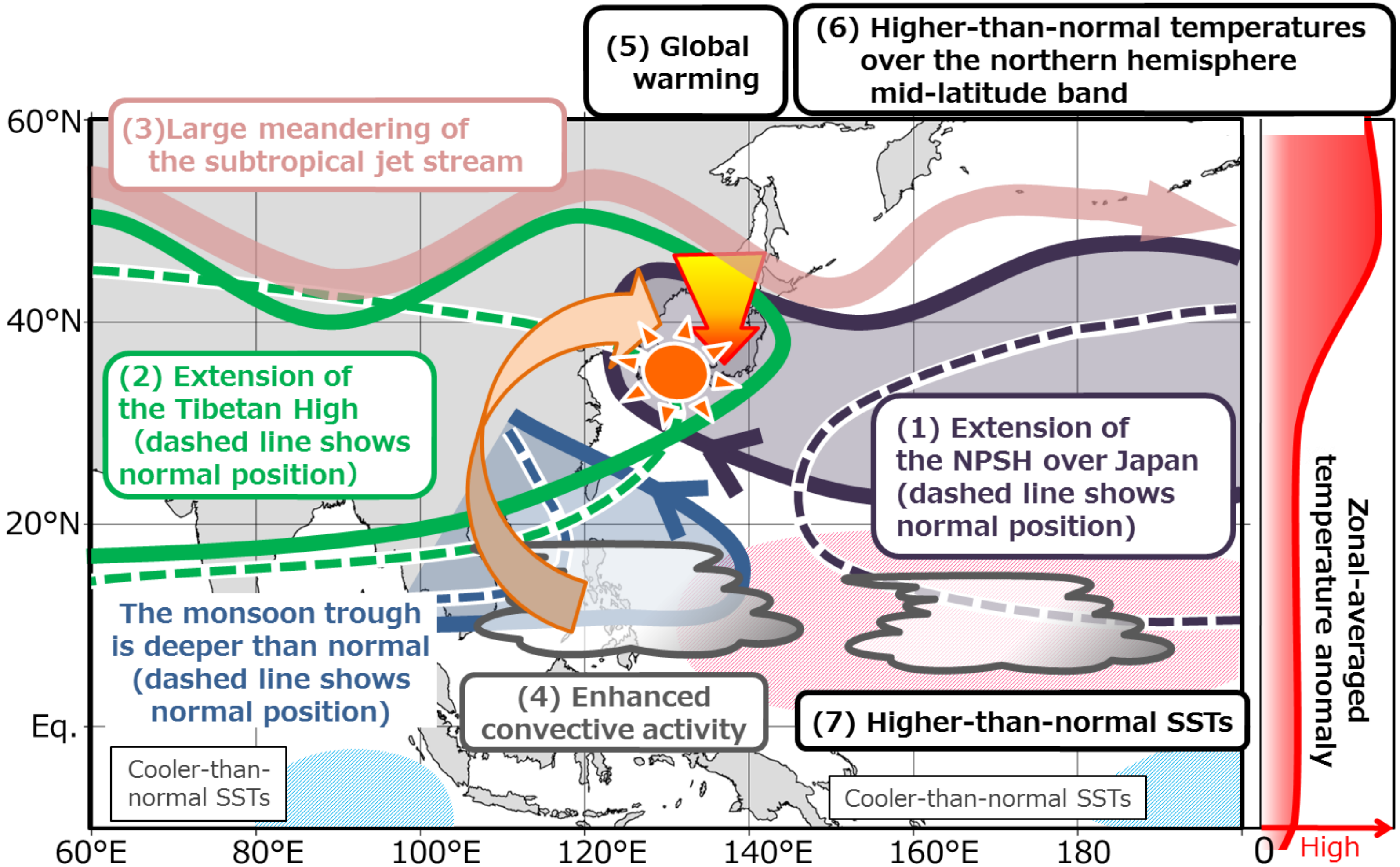


OLR anom [W/m²]



SST anom [°C]

Primary factors behind the unprecedentedly hot conditions observed in boreal summer 2018



Extension of the North Pacific Subtropical High (NPSH) and the Tibetan High over Japan brought extreme high temperatures there through strengthening downward air flow and above-normal sunshine duration.