Climate System Monitoring

Climate Prediction Division of JMA

Hiroshi Hasegawa

(h_hasegawa@met.kishou.go.jp)

Contents

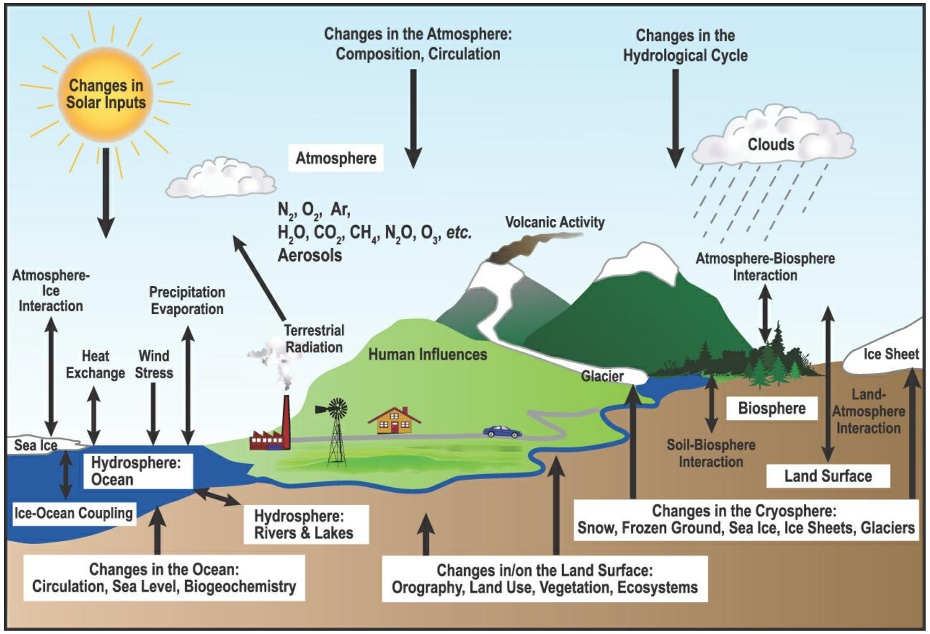
- What is the climate system?
- Purpose of climate system monitoring
- View points for monitoring and analysis
- Data sets for climate system monitoring
- Observational phenomena
  - Seasonal march (annual cycle) of normal condition
  - Anomalies from normal condition
    - ENSO (inter-annual variation)
    - MJO (intra-seasonal variation)
- Products

What is the climate system?

- *Climate*: "The synthesis of the weather"
  - The statistical collection of weather conditions during a specified interval of time.
  - Several decades → normal condition
- Climate system consists of some subsystems, which are atmosphere, ocean, land, biosphere and so on.

In our climate monitoring section, atmospheric general circulation and boundary condition (SST, sea-ice, snow cover, etc.) are monitored.

Time scale: seasonal, monthly, 5-days averaged field (mainly) to monitor large scale phenomena.



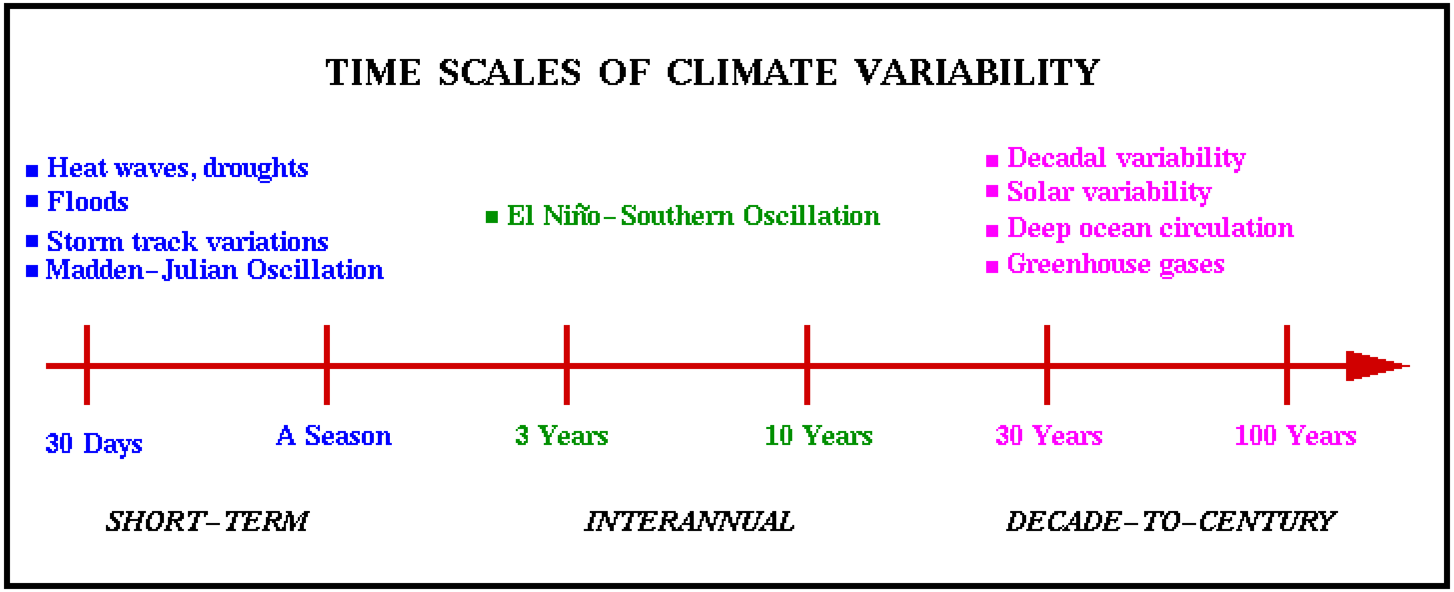
Components of climate system
IPCC (2007)

Purpose of climate system monitoring

- World wide providing the diagnosis information on the climate system as background of extreme climate events
  - (To understand current condition of the climate system)
- Utilizing the information for long range weather forecast
  - (To understand what atmospheric condition or boundary condition in current status influence in the future climate)

View points of monitoring and analysis

- Difference from normal condition (climatological mean)
- Seasonal march (annual cycle)
- Variations (MJO, ENSO, etc.)
- Influence of the tropics on the extra-tropics
- Ocean-atmosphere interaction



http://www.cdc.noaa.gov/

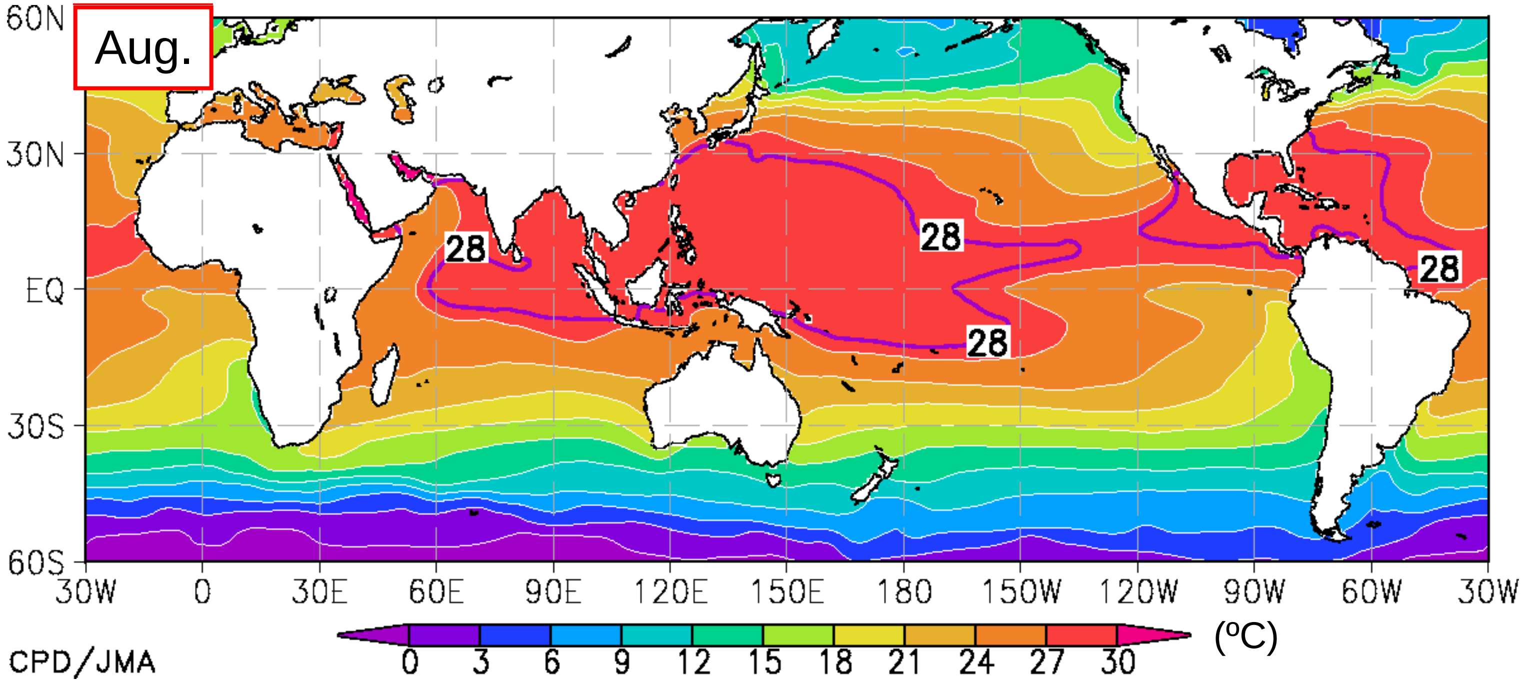
Data for climate system monitoring

- Atmospheric Circulation:
  - Objective analysis data produced by JMA and CRIEPI (JRA-25/JCDAS (Onogi, et. al., 2007))
- Tropical Convection:
  - Outgoing Longwave Radiation (OLR) from NOAA
- Sea Surface Temperature (SST):
  - Analysis data produced in JMA (COBE-SST (Ishii, et. al., 2005))
- Snow Cover and Sea Ice:
  - Observations with SSM/I onboard the DMSP polar orbiting satellites from NOAA

Contents

- What is the climate system?
- Purpose of climate system monitoring
- View points for monitoring and analysis
- Data sets for climate system monitoring
- Observational phenomena
  - Seasonal march (annual cycle) of normal condition
  - Anomalies from normal condition
    - ENSO (inter-annual variation)
    - MJO (intra-seasonal variation)
- Products

Sea Surface Temperature (SST)



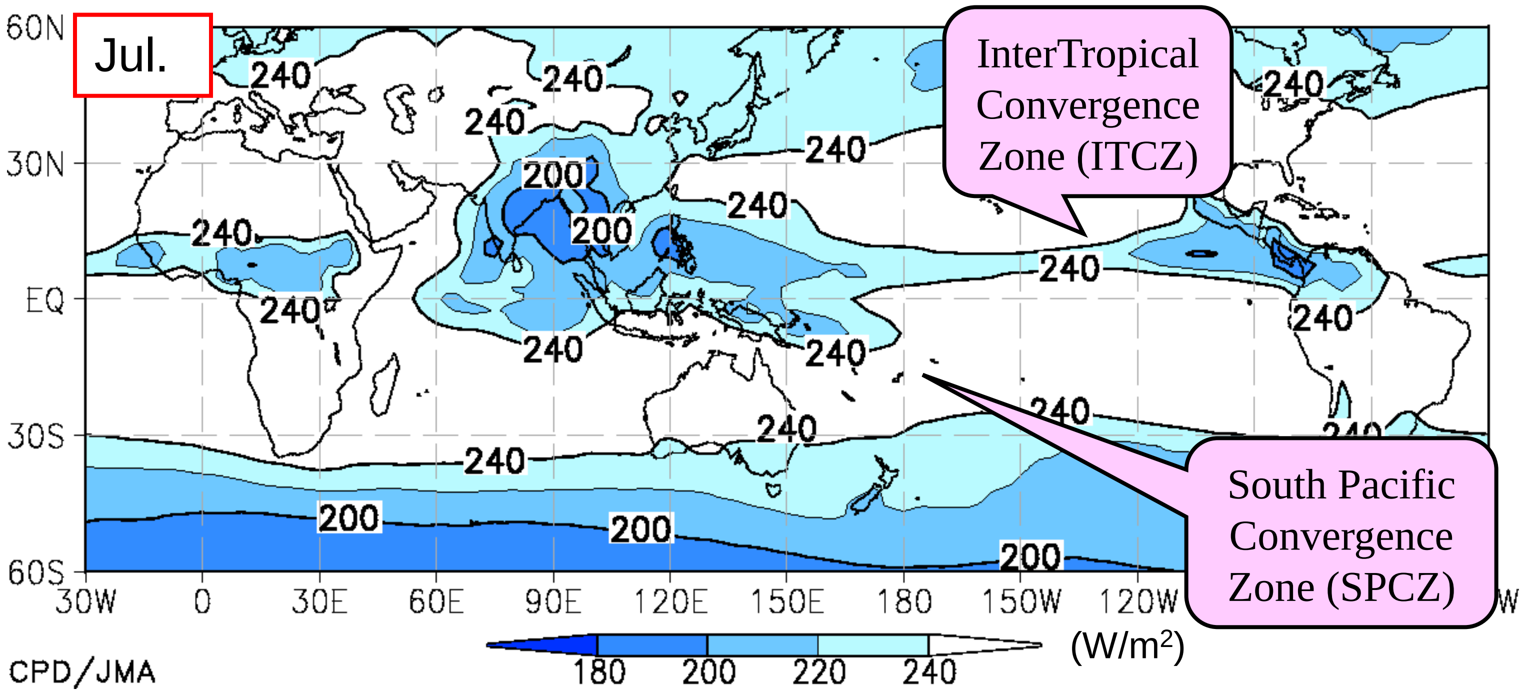
Monthly mean SST (1971 – 2000 mean)

Purple line indicates 28ºC isotherm.

In general, SST decreases from west to east over the Pacific, and from east to west over the Indian Ocean.

Once ENSO event occurs, these distributions are changed basin-wide.

Tropical convection
← Outgoing Longwave Radiation (OLR)

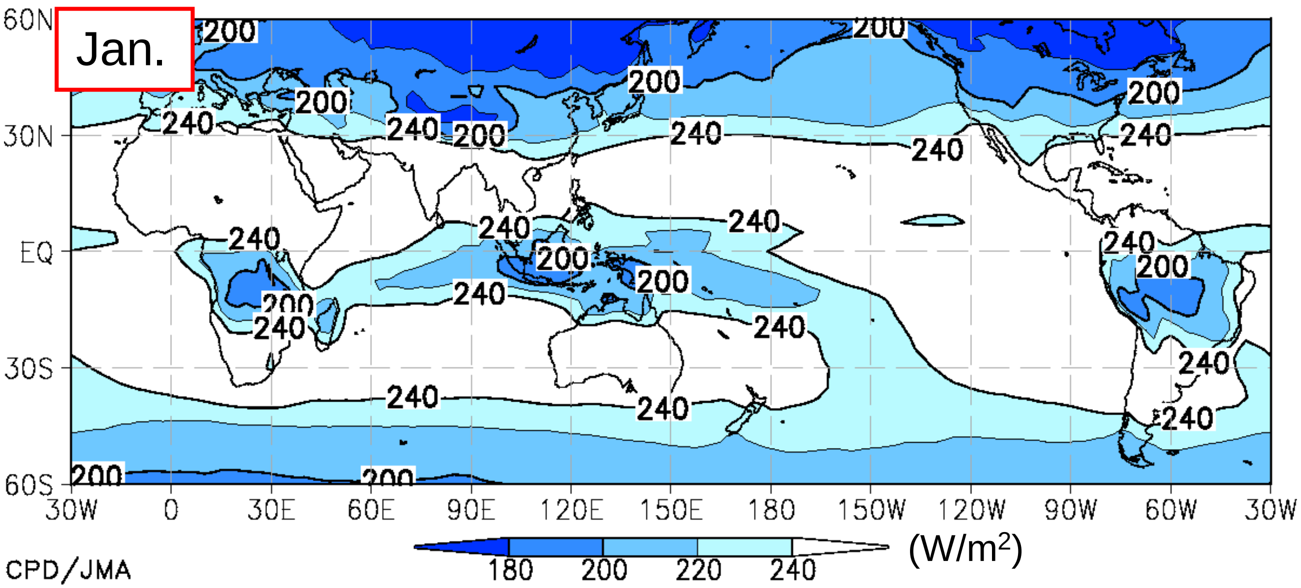


Monthly mean OLR (1979 – 2004 mean)

In the tropics, lower OLR indicates active convection (convective cumulus). In the high latitude zone, OLR indicates only cooler region.

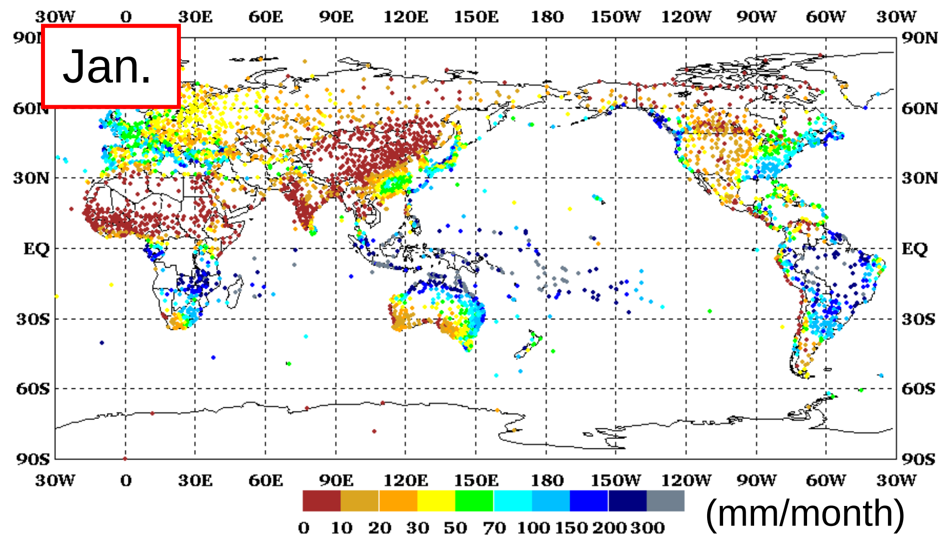
Major active convection area: equatorial Africa, around Maritime Continent, South America

OLR ⇔ Precipitation



Monthly mean OLR (1979 – 2004 mean)

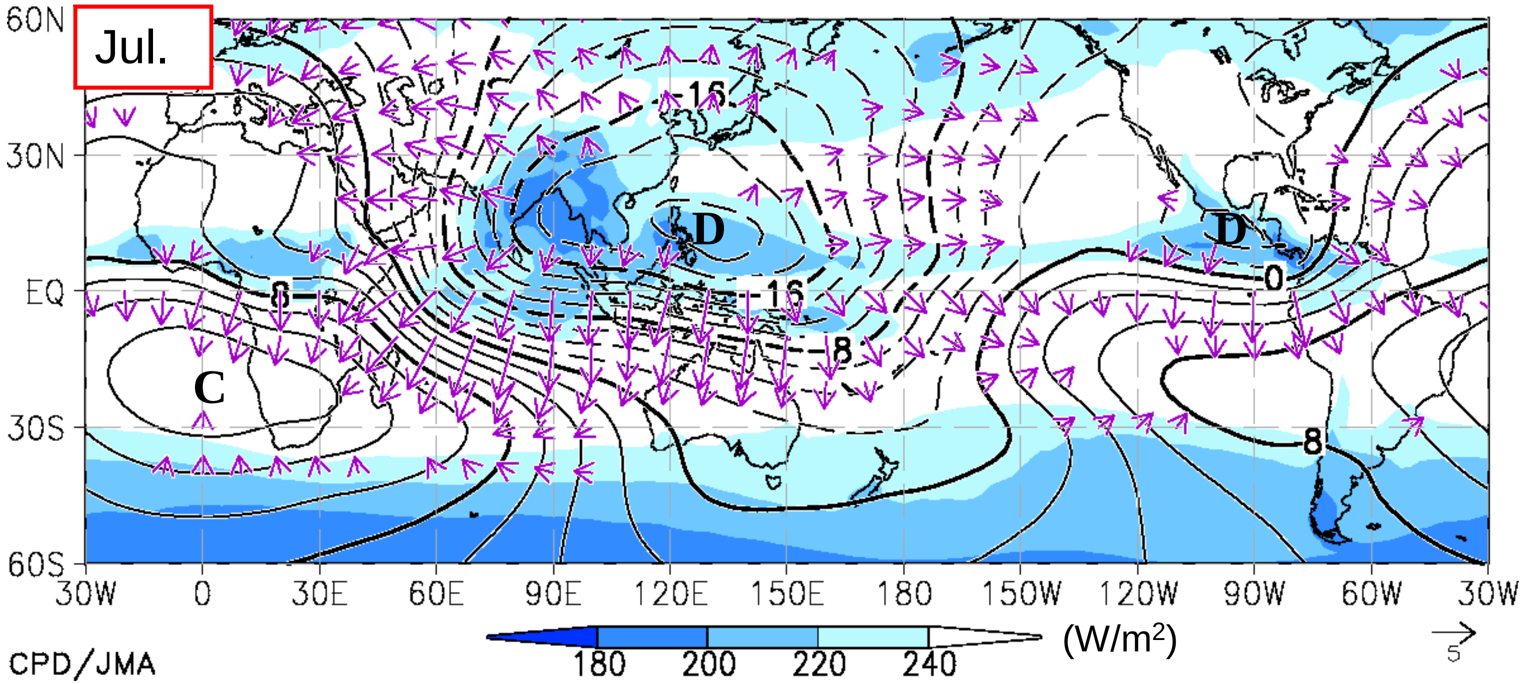
Monthly mean Precipitation amount (1971 – 2000 mean)



In the tropics, OLR generally corresponds to the precipitation amount.

200-hPa Velocity potential

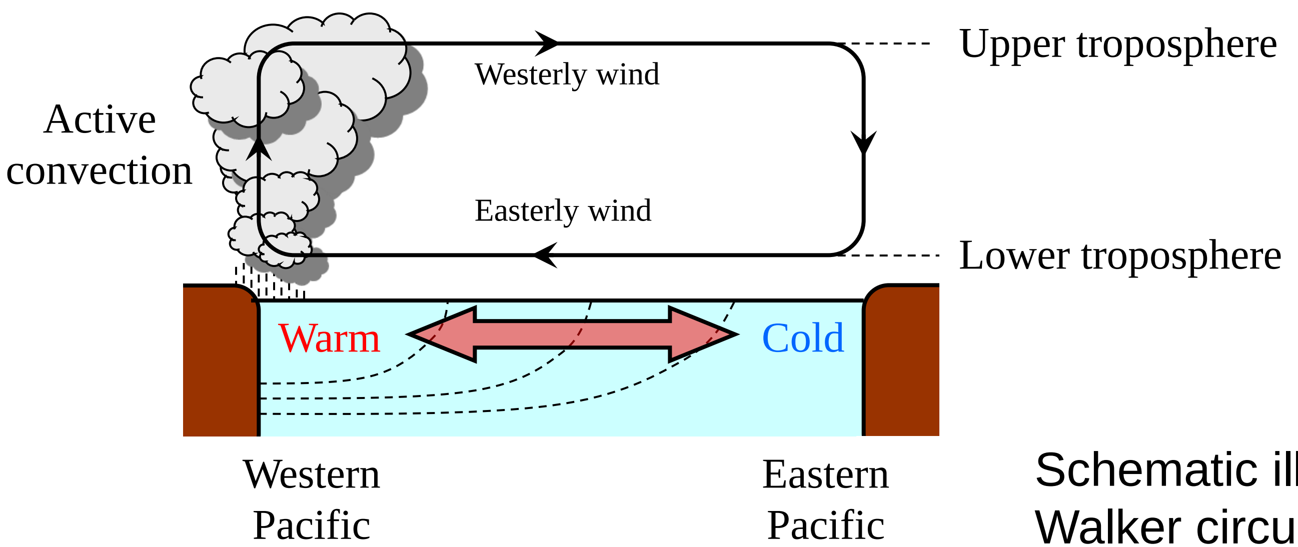
- Velocity potential is related with large scale divergent wind.
- Lower Velocity potential corresponds to active convection (JMA definition).
  - Divergent wind blow from lower Velocity potential area to higher Velocity potential area across contour.



Monthly mean 200-hPa Velocity potential (contours, ×$10^6 m^2/s$), OLR (shadings, W/m^2) and 200-hPa divergent wind (vectors, m/s) (1979 – 2004 mean)

Tropical convection & Walker circulation

- *Walker circulation*: Vertical-Zonal circulation along the equator
  - Ascending motion is found over the western Pacific, and descending motion over the eastern Pacific.
  - In El Niño event, active convection area shifts eastward and Walker circulation is weakened while it is strengthened in La Niña event.

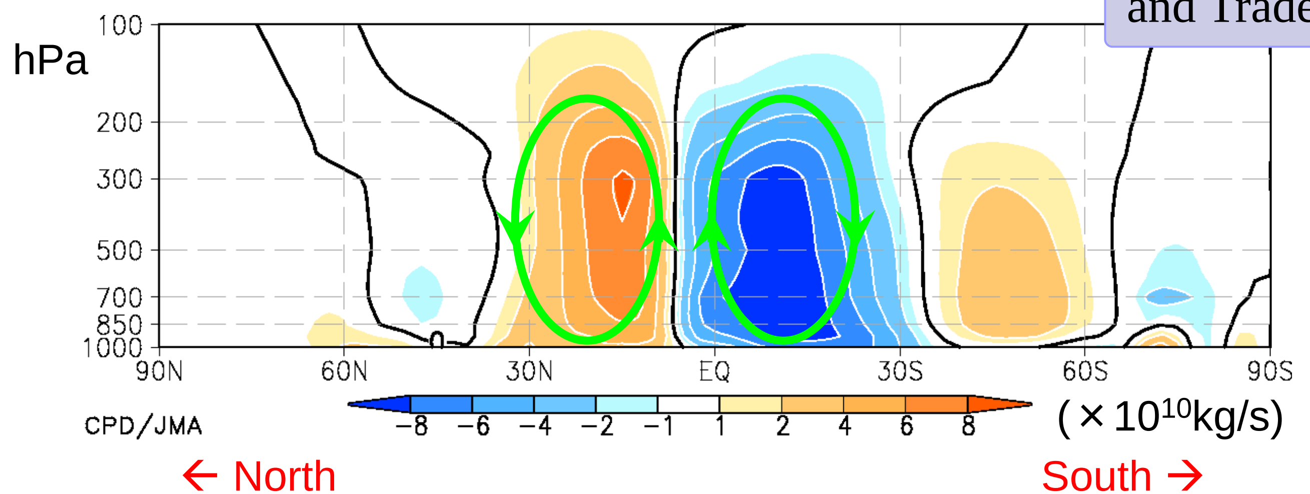


Schematic illustration of Walker circulation

Tropical convection & Hadley circulation

- *Hadley circulation*: Vertical-Meridional circulation
  - Ascending near the equator and descending in the subtropics (around 30ºN(S))
  - Hadley cells shift north- and southward in association with seasonal march.

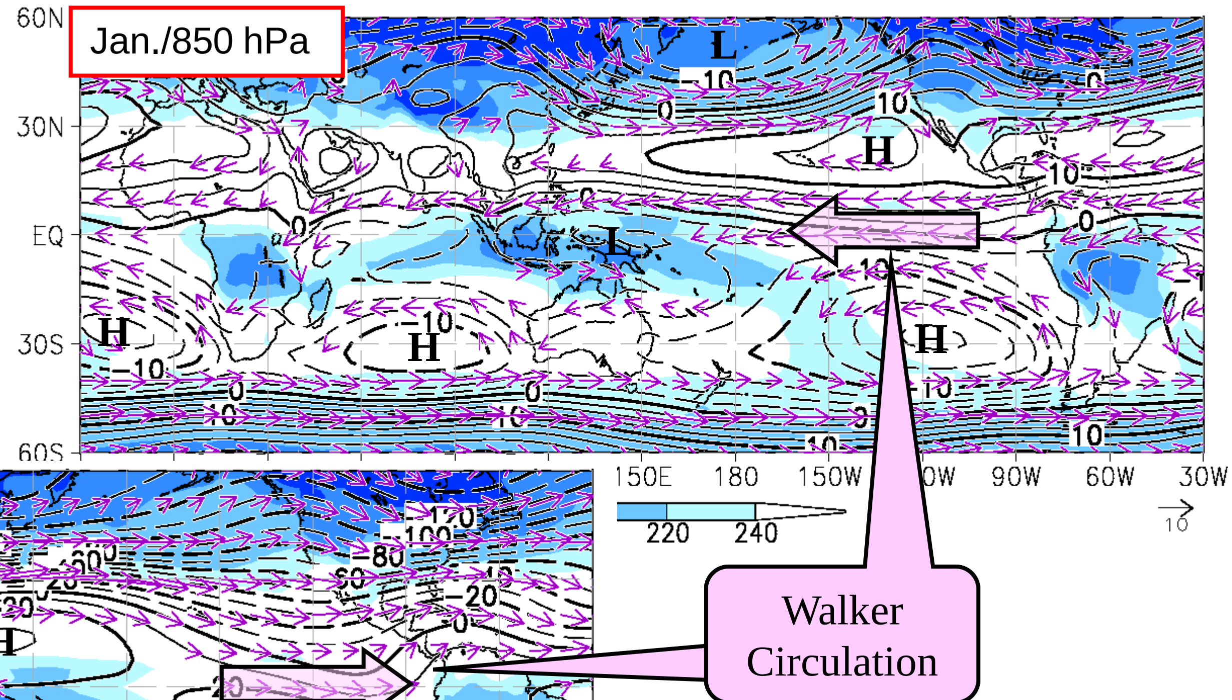
Descending contribute to formation of Subtropical High and Trade Wind.

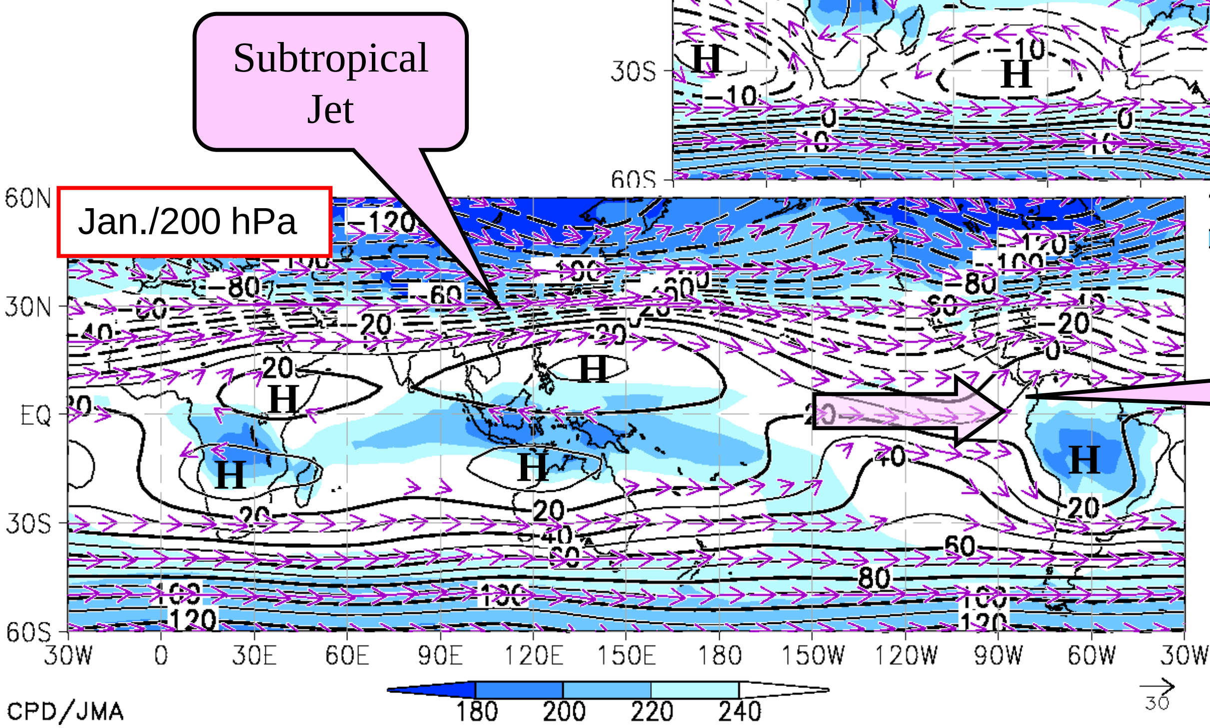


Annual mean mass stream function (zonal mean)

Stream function (Jan.)

- Stream function gradient corresponds to wind speed.
- Wind blows parallel to Stream function seeing larger value on the right side.

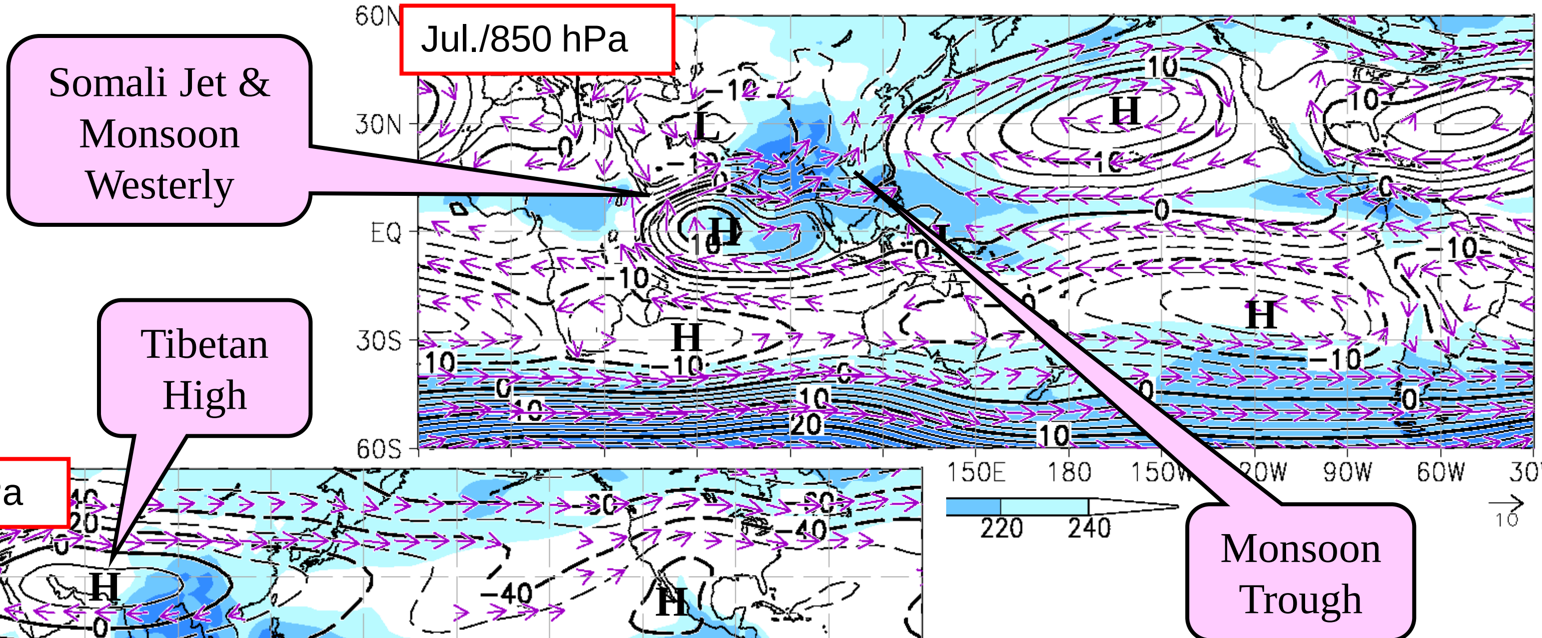


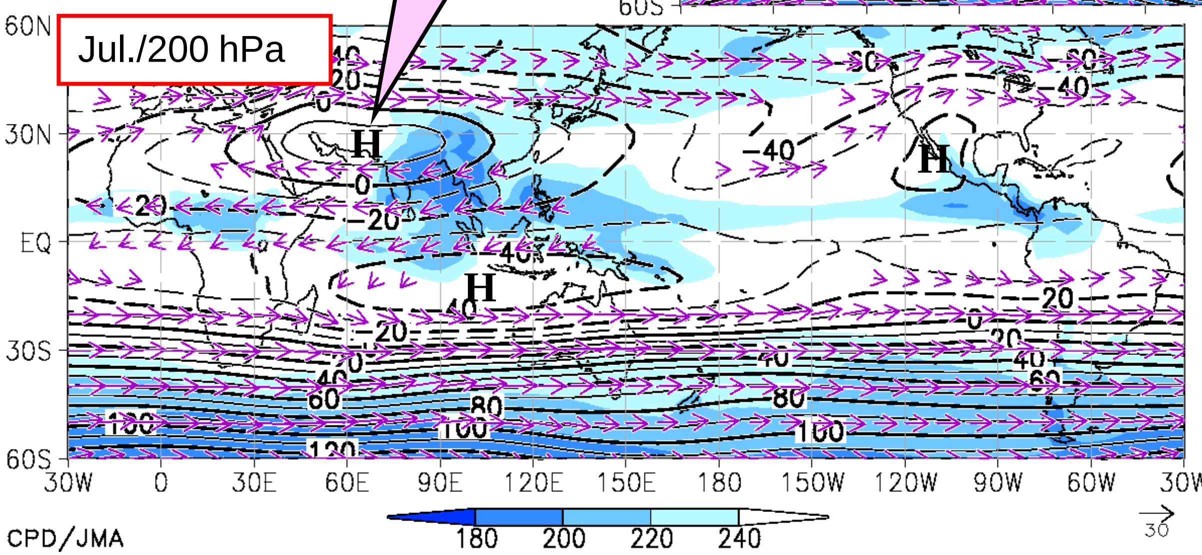


Monthly mean 850- (top) & 200- (bottom) hPa Stream function (contours, $\times 10^6 m^2/s$), OLR (shadings, W/m^2) and wind (vectors, m/s) (1979 – 2004 mean)

Stream function (Jul.)

- In boreal summer, Asian summer monsoon circulations are developed.
- Tibetan High is formed associated with strongly heated Tibetan Plateau.

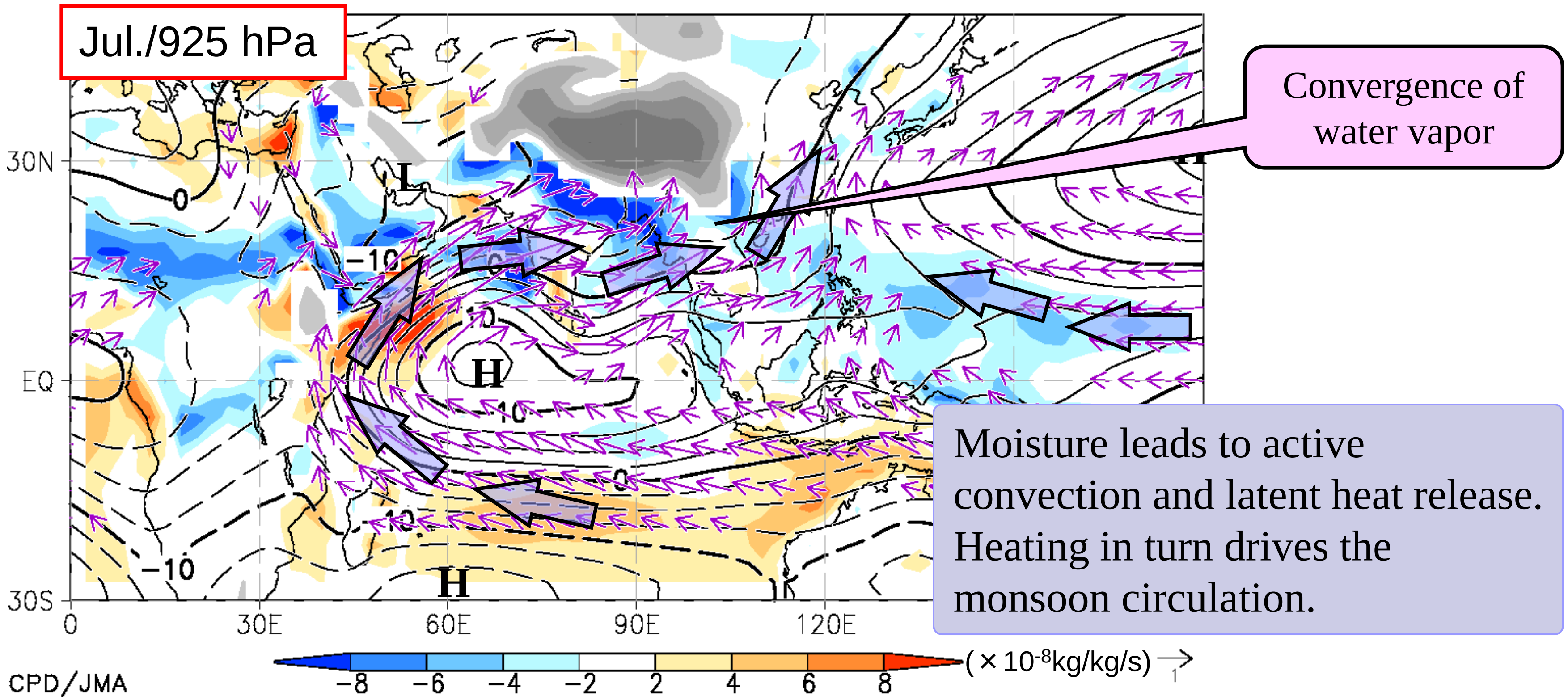




Monthly mean 850- (top) & 200- (bottom) hPa Stream function (contours, $\times 10^6 m^2/s$), OLR (shadings, W/m^2) and wind (vectors, m/s) (1979 – 2004 mean)

Asian summer monsoon

- Asian summer monsoon is a large scale motion with moisture transport from Southern Hemisphere to South and East Asia.

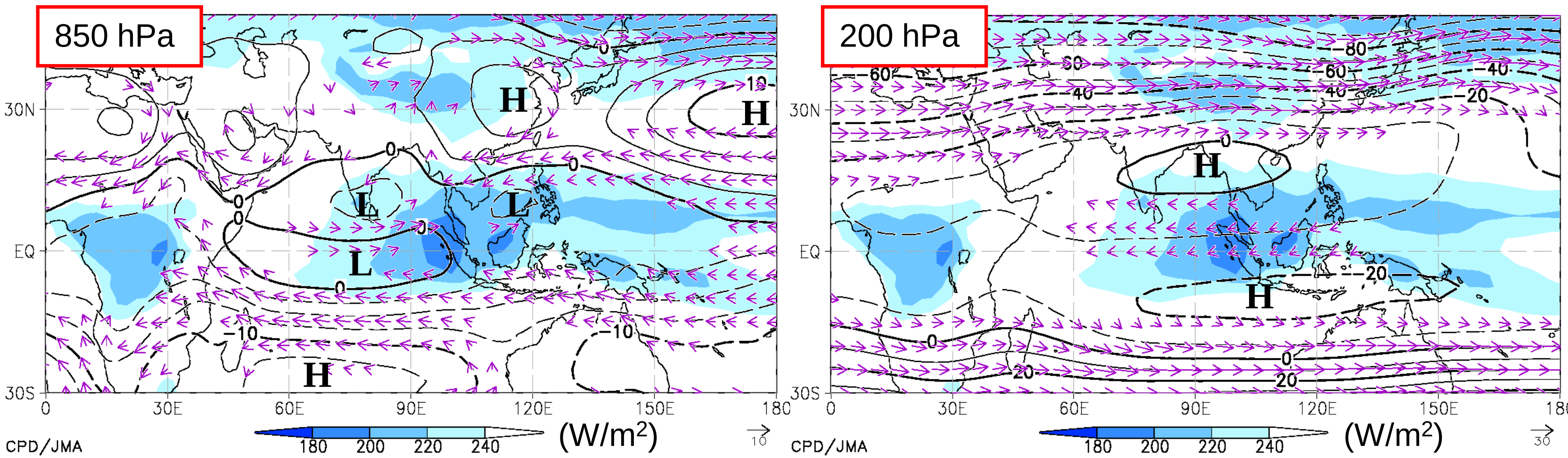


Monthly mean 925-hPa Stream function (contours, ×$10^6 m^2/s$), divergence of Water vapor flux (shadings, ×10^{-8}kg/kg/s) and Water vapor flux (vectors, m/s*kg/kg) (1979 – 2004 mean) Gray shadings show topography (≥1500 m).

Seasonal march of Asian summer monsoon

- Onset: mid-May over Indochina Peninsula
- Withdrawal: mid-October
- Mature phase: July – August
- Monsoon has an active-break cycle (not observed in normal condition).
- Monsoon brings rainy season also in East Asia (ex. *Bai-u* in Japan).

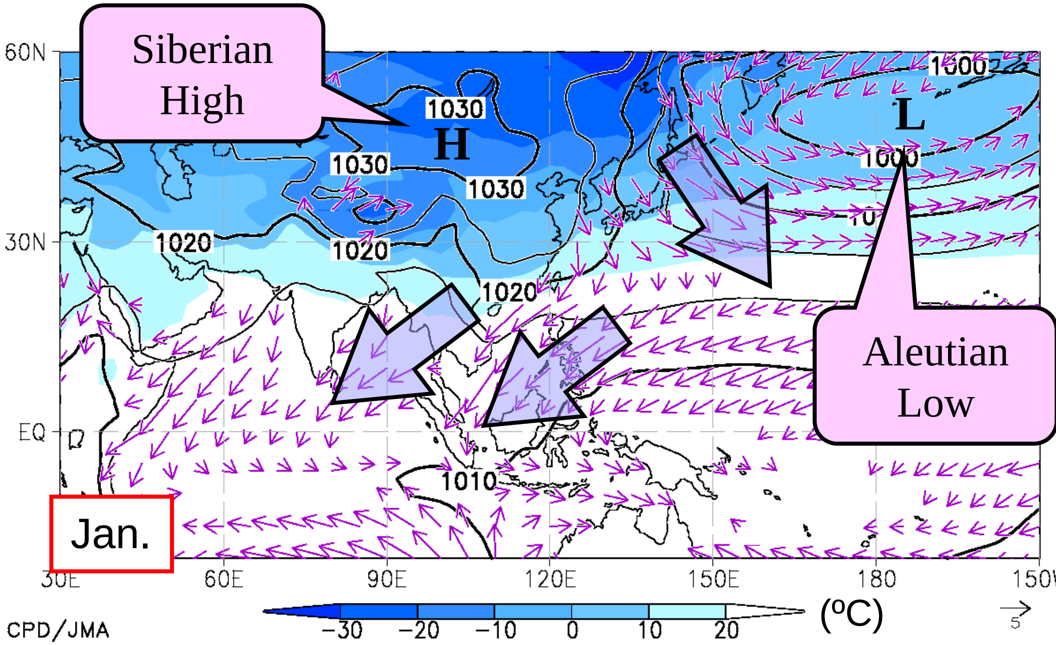
October



Monthly mean 850- (left) & 200- (right) hPa Stream function (contours, $\times 10^6 m^2/s$), OLR (shadings, W/m^2) and wind (vectors, m/s) (1979 – 2004 mean)

Asian winter monsoon

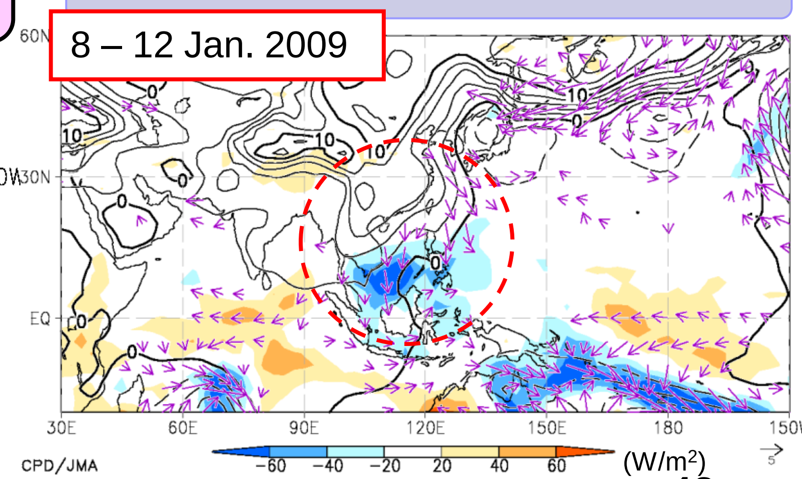
- In boreal winter, Siberian High and Aleutian Low are developed.
  - North-westerlies to East Asia, North-easterlies to South Asia



Monthly mean surface 2 m temperature (shadings, ºC), Sea Level Pressure (contours, hPa) and surface 10 m wind (vectors, m/s) (1979 – 2004 mean)

Sometimes, north-easterlies bring "Cold Surge" over South Asia.

→ enhanced convection and cold weather



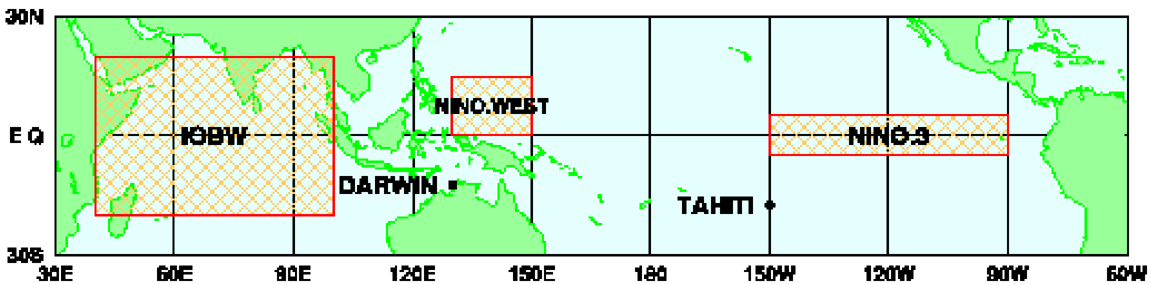
Shadings: OLR anomalies

Contents

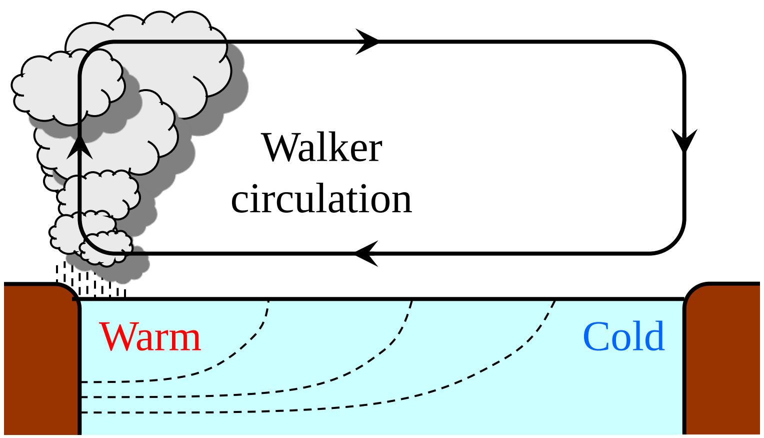
- What is the climate system?
- Purpose of climate system monitoring
- View points for monitoring and analysis
- Data sets for climate system monitoring
- Observational phenomena
  - Seasonal march (annual cycle) of normal condition
  - Anomalies from normal condition
    - ENSO (inter-annual variation)
    - MJO (intra-seasonal variation)
- Products

El Niño Southern Oscillation (ENSO)

- In El Niño event, SST rise over from the central to east Pacific around equator. Active convection area shifts eastward from normal position.
- JMA monitors “NINO.3”, “NINO.WEST” and “IOBW (Indian Ocean)” region.
  - The eastern, the western Pacific and Indian Ocean have the variations linked with each other.



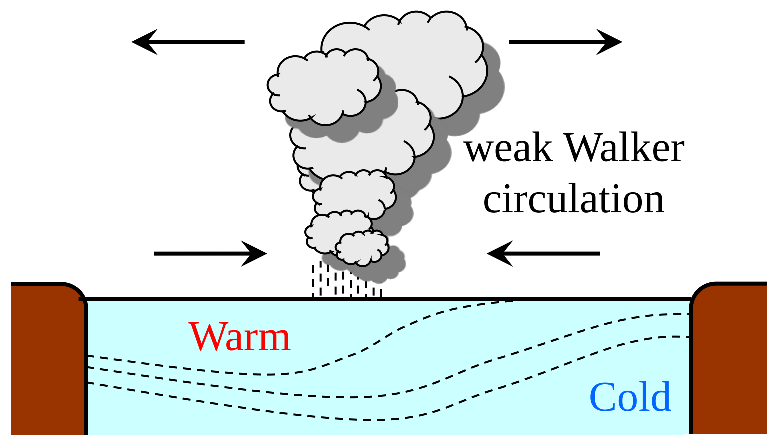
Monitoring region



Western Pacific

Eastern Pacific

Normal (or La Niña)



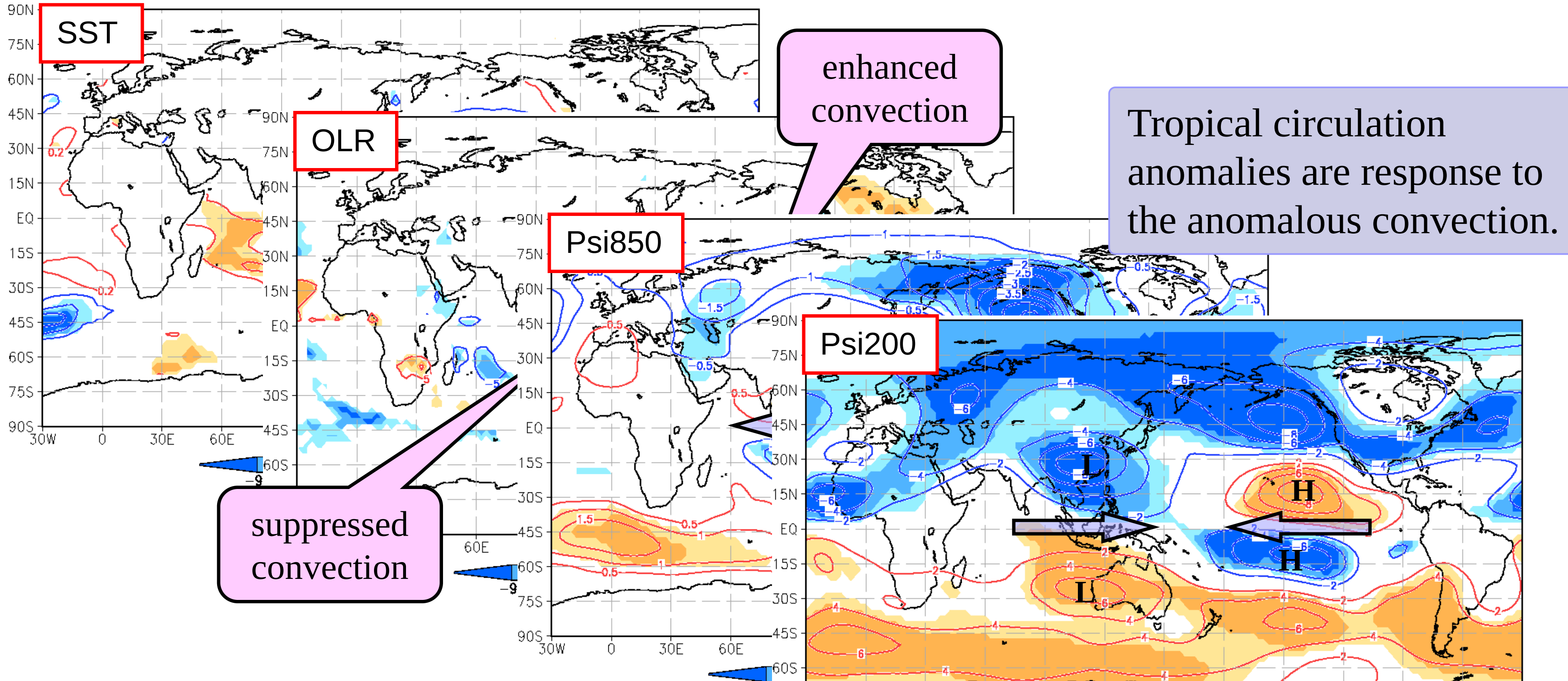
Western Pacific

Eastern Pacific

El Niño

Atmospheric features in El Niño

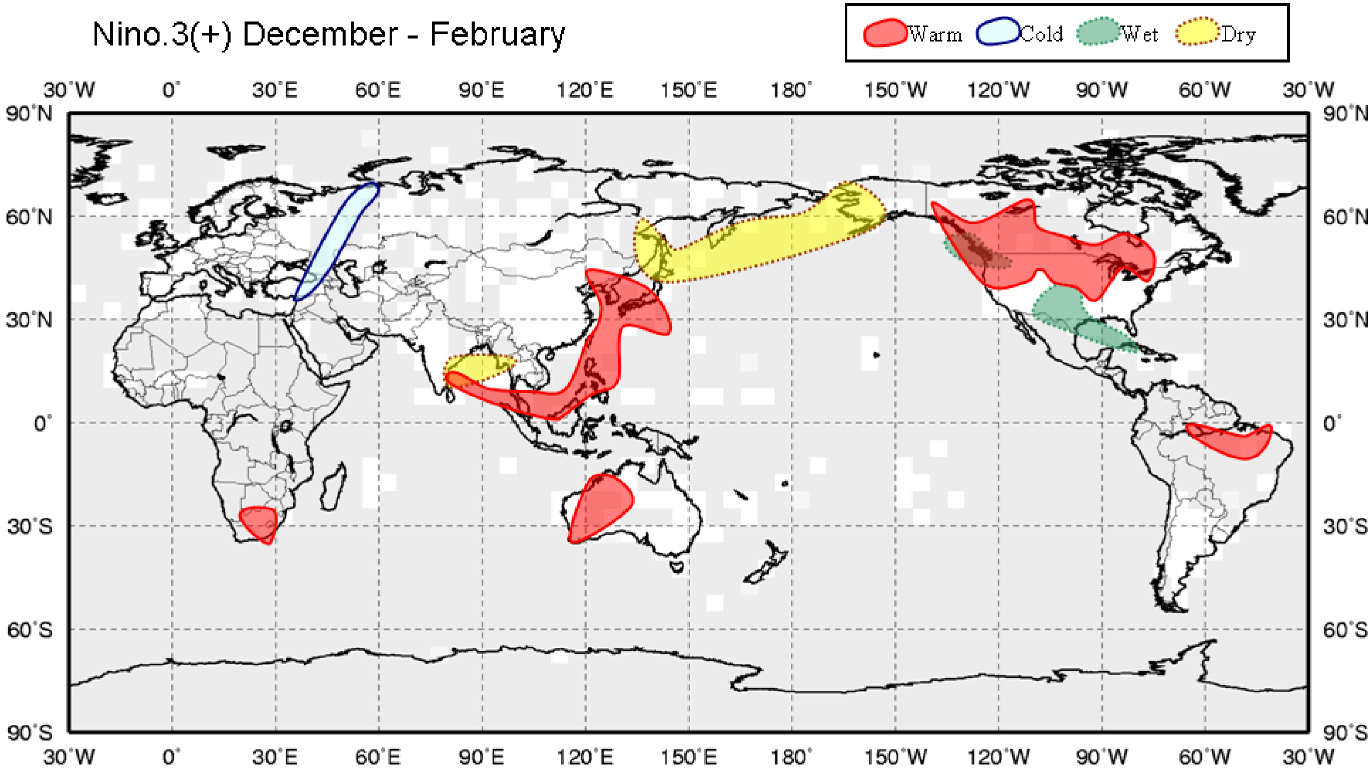
- ENSO influence is most clear in boreal winter.
- Statistical tendencies in the past ENSO events → Composite Map



Composite maps in El Niño phase (Dec. – Feb.)
Contours: anomaly, Shadings: statistical significant region, Statistical period: 1979 – 2009, NINO.3≥+0.5ºC.

Influence on world weather

- ENSO influences the world weather not only in the tropics but also in the extra-tropics (mid- & high-latitude zone).

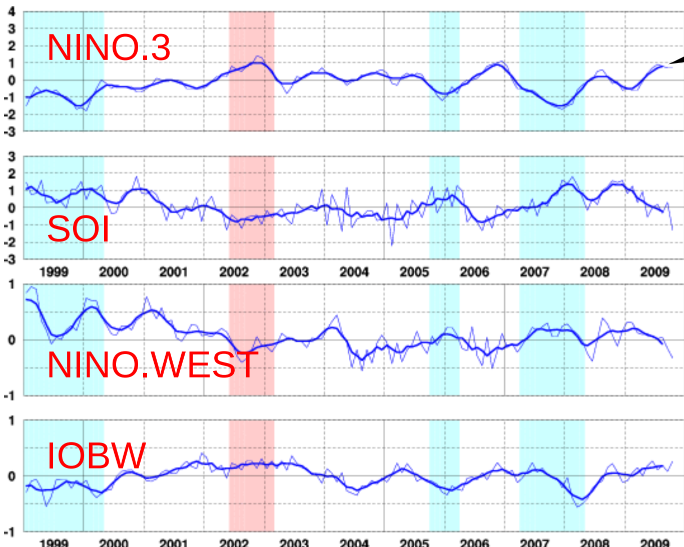


Climate tendencies in El Niño phase (Dec. – Feb.)
Gray shadings: no enough data, Statistical period: 1979 – 2009, NINO.3≥+0.5ºC.

El Niño event (Jun. 2009 ~)

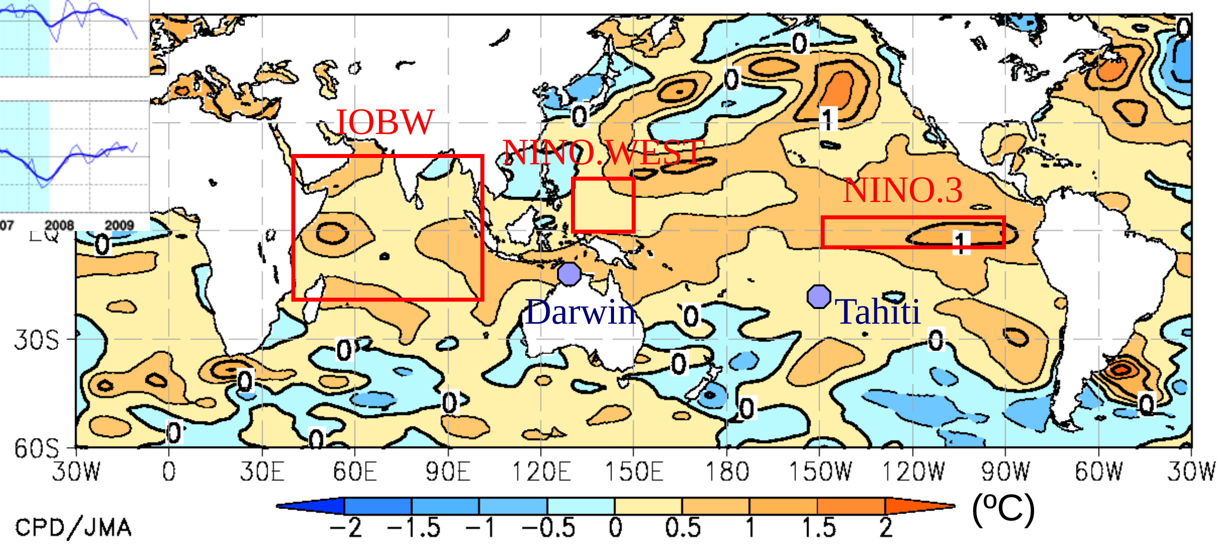
- El Niño condition has continued since boreal summer.
- Negative SST anomalies are not observed over the western Pacific.
  - Positive SST anomalies prevail over the tropics.

+0.7ºC



Time series of monitoring Indices

3-month mean SST anomalies (Jun. – Aug. 2009)



Contents

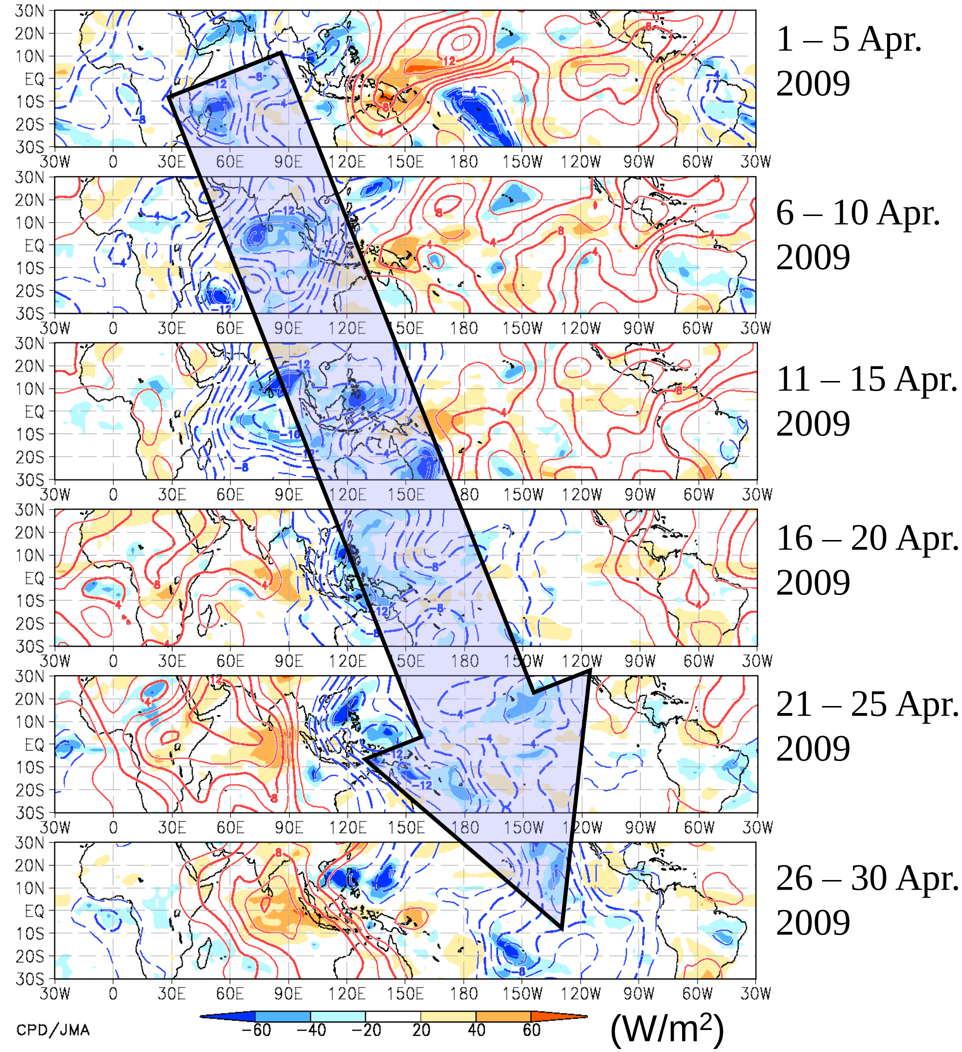
- What is the climate system?
- Purpose of climate system monitoring
- View points for monitoring and analysis
- Data sets for climate system monitoring
- Observational phenomena
  - Seasonal march (annual cycle) of normal condition
  - Anomalies from normal condition
    - ENSO (inter-annual variation)
    - MJO (intra-seasonal variation)
- Products

Madden-Julian Oscillation (MJO)

- MJO is intra-seasonal variation found by Madden and Julian in 1971.
- Large scale anomalous rainfall patterns propagate eastward over the equator for the period 30 – 60 days.

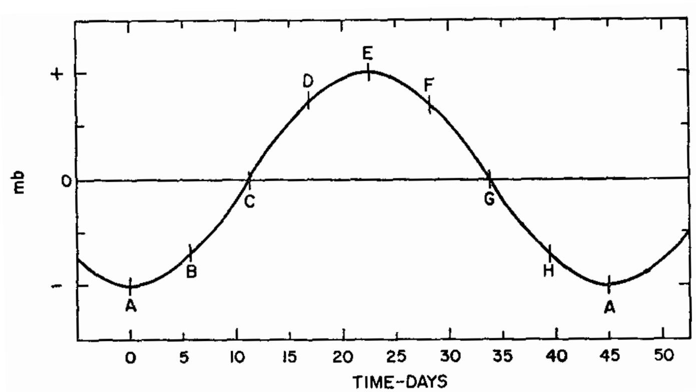
→ Large scale divergent anomalies in the upper troposphere also propagate eastward.

5-day mean OLR anomalies (shadings) and 200-hPa velocity potential anomalies (contours) in April 2009

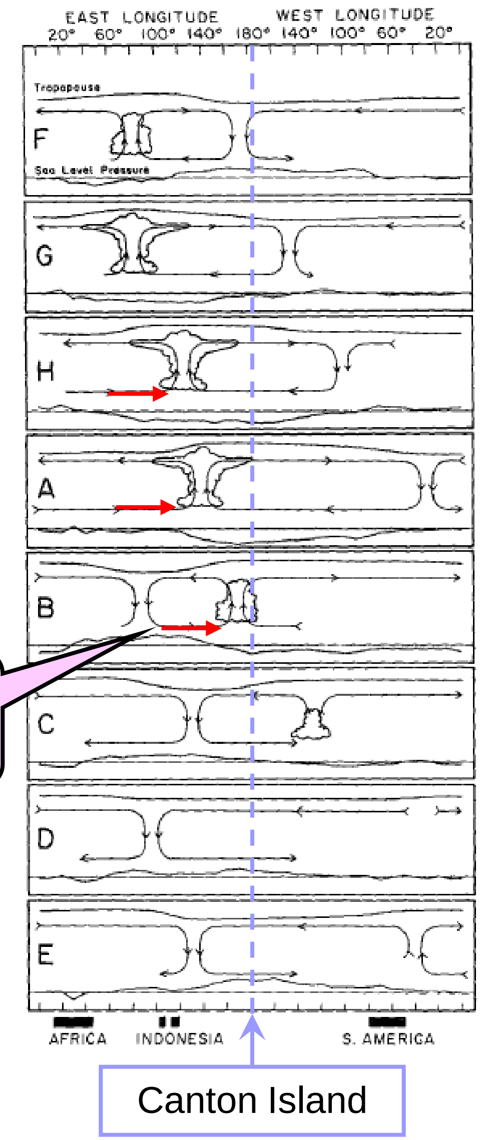


Madden-Julian Oscillation (MJO)

- As active phase of MJO propagates eastward, atmospheric circulation is modulated.
- MJO tends to be clear from Indian Ocean to the western Pacific.
- Westerly burst is modulated sometimes.
  - Trigger for El Niño?



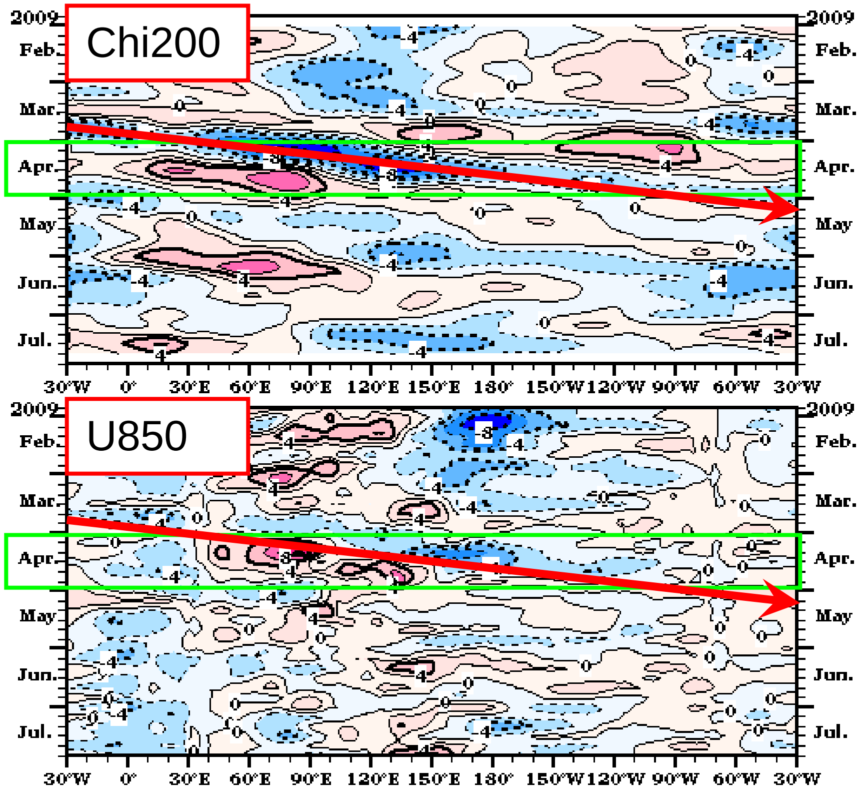
Idealized depiction of simple pressure wave in the Canton time series
Madden and Julian (1972)



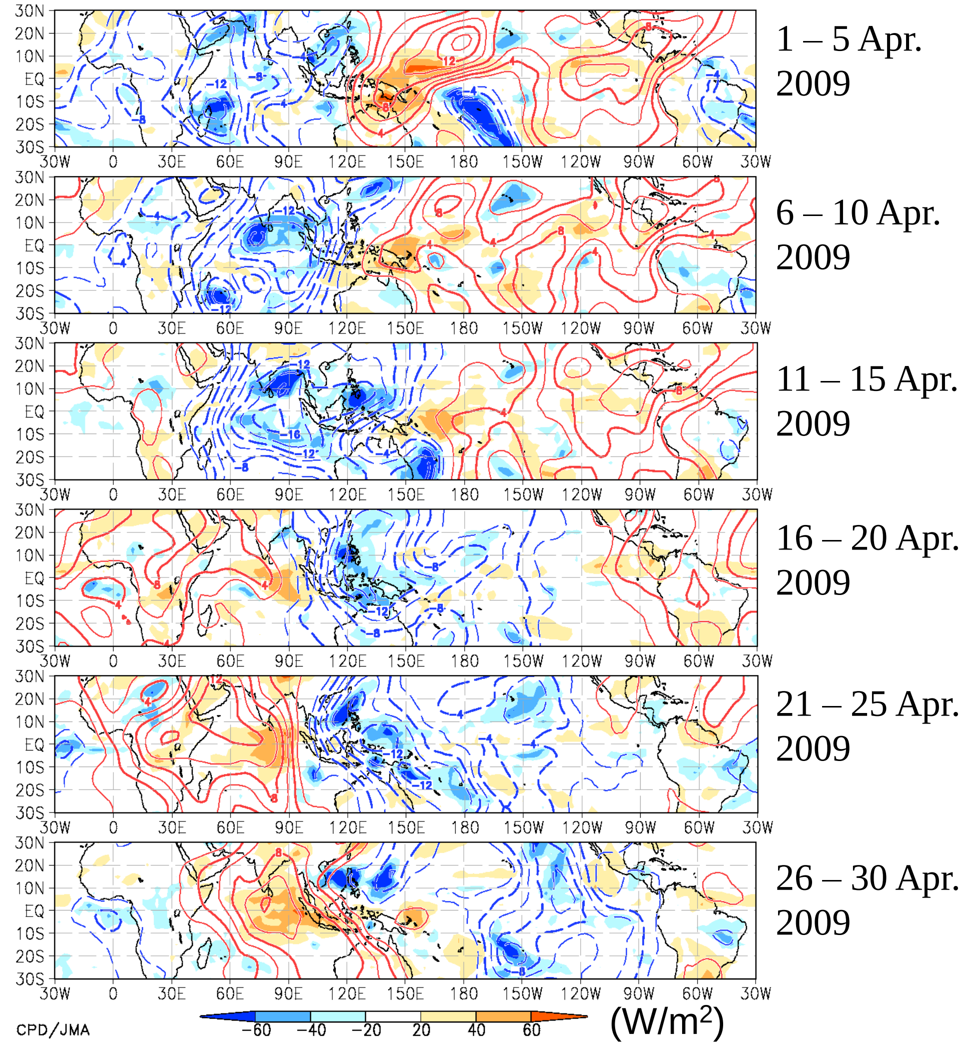
Schematic depiction of MJO
Madden and Julian (1972)

MJO Monitoring

- Hovmellör diagram
  - Time-longitude cross section



Time-longitude cross section of 200-hPa velocity potential (top) and 850-hPa zonal wind (bottom) anomalies (5ºS – 5ºN)



MJO Monitoring

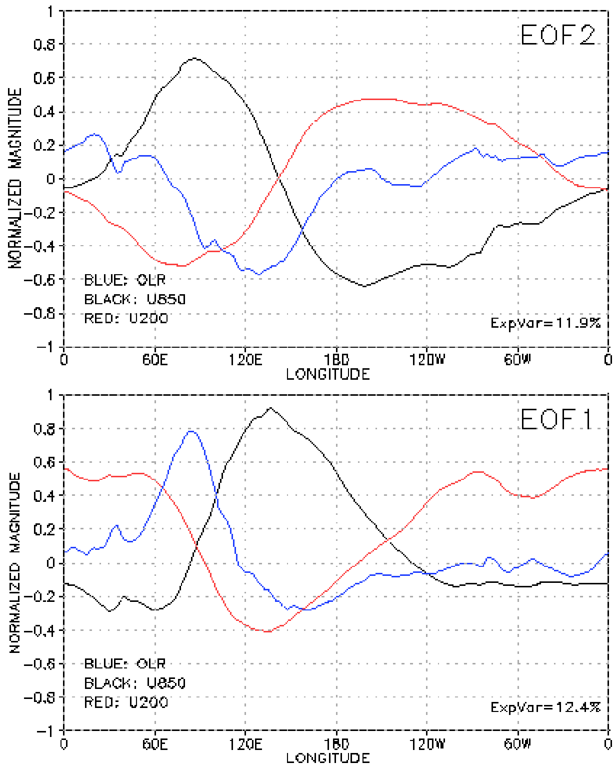
- Wheeler and Hendon (2004) developed MJO index: Real time Multivariate MJO series (RMM1, RMM2)
  - RMM1 and RMM2 are the pair of EOF time series of the MJO components of 850-hPa, 200-hPa zonal wind and OLR (near the equator).

How to calculate RMMs?

1. Extract the MJO components by subtracting ENSO, seasonal and inter-annual variability.

2. Operate Multivariate EOF analysis to the MJO components.

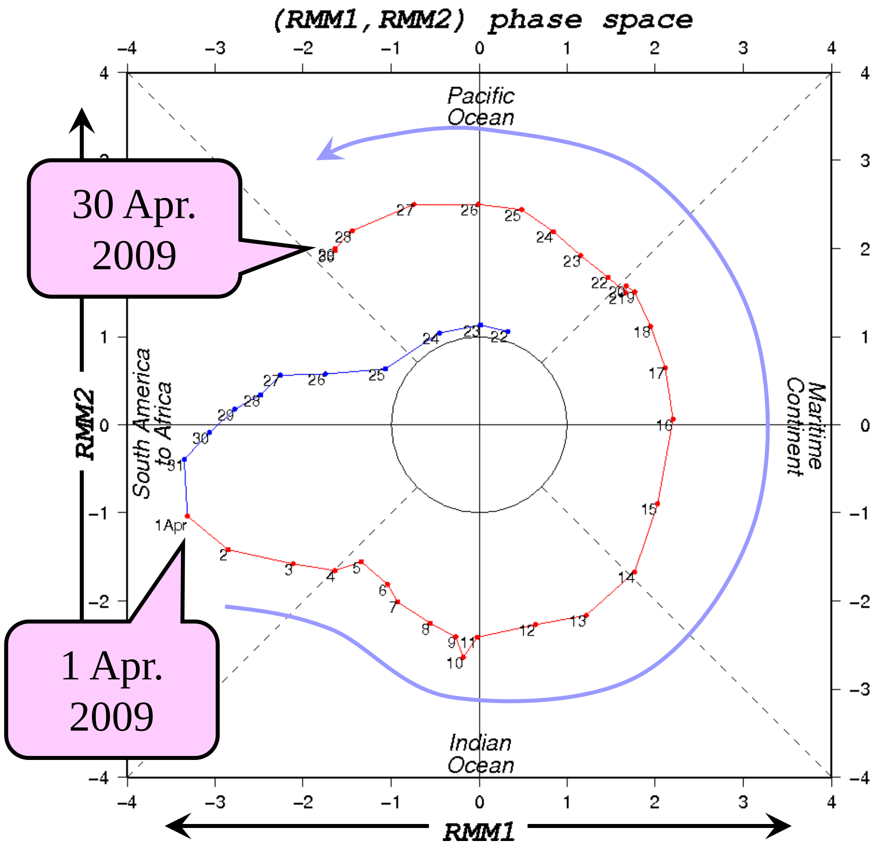
3. Project the daily observed data onto the multivariate EOFs, with the each variability removed. → yields RMM1 and RMM2



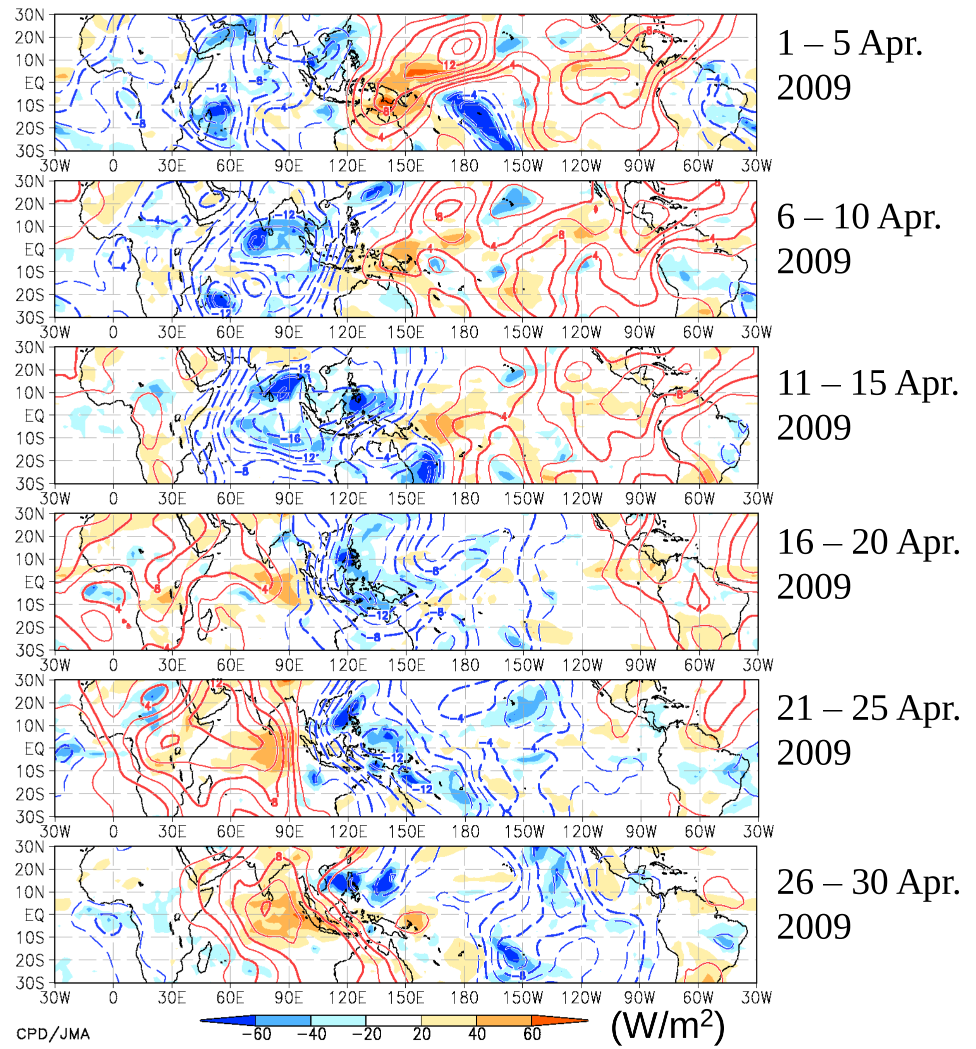
Multivariate EOFs (eigen vector)

MJO Monitoring

4. Plot the RMM1 and RMM2 on the phase space. → "*Phase Monitor*"



MJO phase monitor
Blue: Mar. 2009, Red: Apr. 2009



Contents

- What is the climate system?
- Purpose of climate system monitoring
- View points for monitoring and analysis
- Data sets for climate system monitoring
- Observational phenomena
  - Seasonal march (annual cycle) of normal condition
  - Anomalies from normal condition
    - ENSO (inter-annual variation)
    - MJO (intra-seasonal variation)
- Products

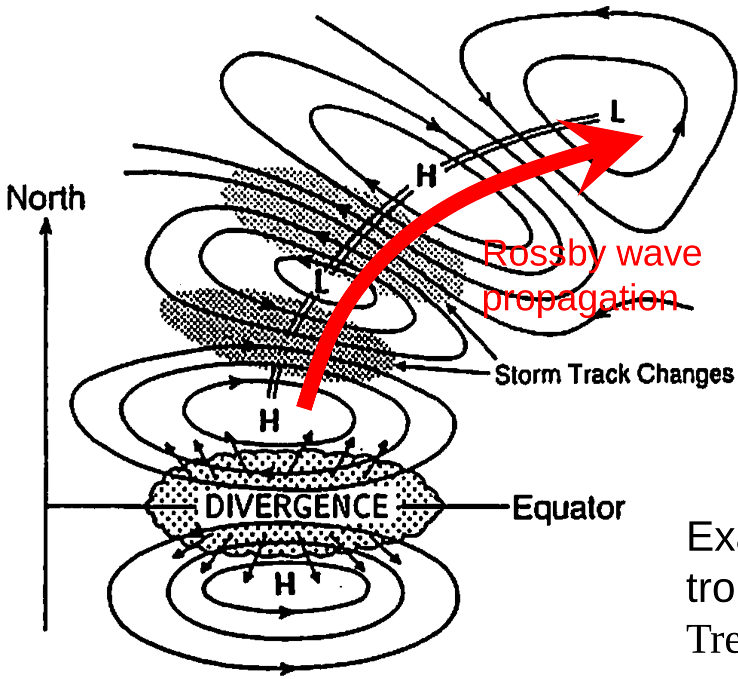
Products

- Online Products: can get each information in Tokyo Climate Center (TCC) web site. http://ds.data.jma.go.jp/tcc/tcc/index.html
  - Climate System Monitoring
    - Report on Climate System
    - Asian Monsoon Monitoring
    - MJO Monitoring
    - Statistical Research … etc.
  - El Niño Monitoring
- Offline Products: CD (DVD) –ROM and book
  - Annual Report on Climate System
  - Data Report on Climate System

Thank you !

Teleconnection

- *Teleconnection*: correlation between the flows at remote locations
  - Major patterns (through propagation of Rossby wave)
    - Wavetrains pattern: alternating ±anomalies along a great circle passing (ex. Pacific/North American (PNA) pattern)
    - Dipole pattern: meridional oscillation (ex. Arctic Oscillation (AO))
  - Sometimes indicate connections between the tropical and mid-latitude low frequency transients.
    - Response to heat source in the tropics



Heat source (positive SST anomalies and active convections) results in divergent wind in the upper troposphere.

The divergent wind forms anti-cyclone pair and excites Rossby wave.

Example of wavetrains excited by the tropical heat source (upper troposphere)
Trenberth and Branstator (1998)

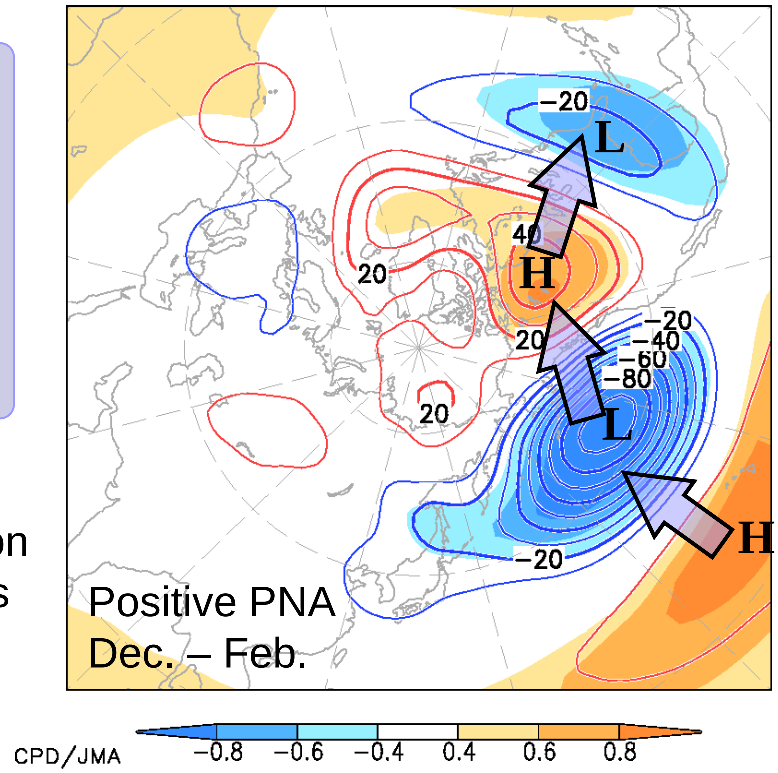
Teleconnection

- Pacific/North American (PNA) pattern
  - One of the most prominent Teleconnection in the Northern Hemisphere.
  - Influences the jet streams and the blocking activities over North Pacific and North American regions.
  - Response to the tropical Pacific SST and convections

PNA-index = 0.25 × { Z^*(20N,160W)
– Z^*(45N,165W) + Z^*(55N,115W)
– Z^*(30N,85W)}

Z^*: 500-hPa height anomaly

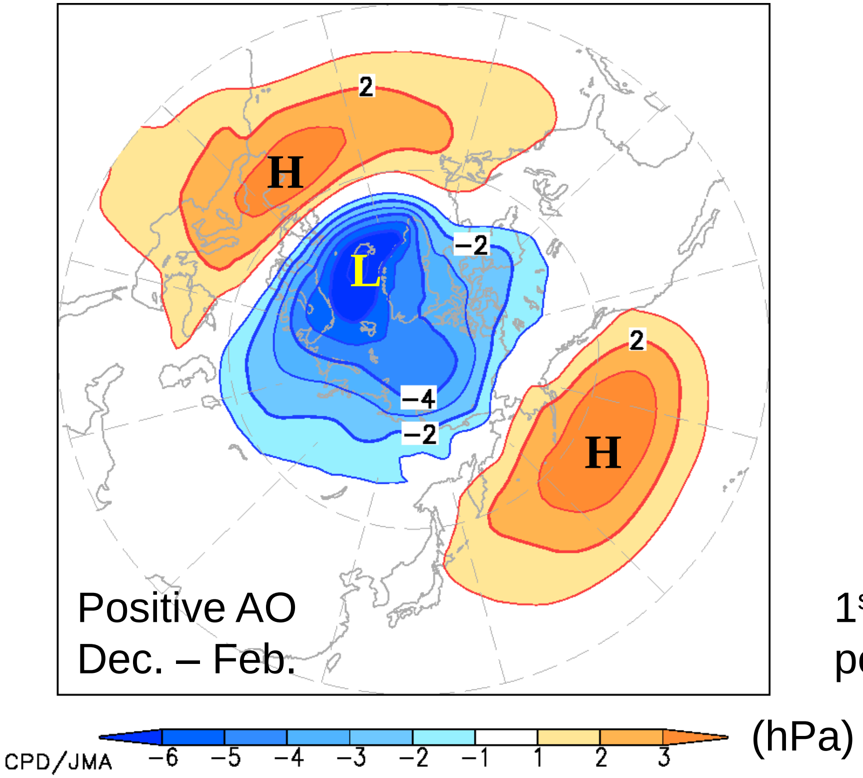
(Wallace and Gutzler, 1981)



Regression (contours, m) and correlation (shadings) of 500-hPa height anomalies for PNA-index (boreal winter)

Teleconnection

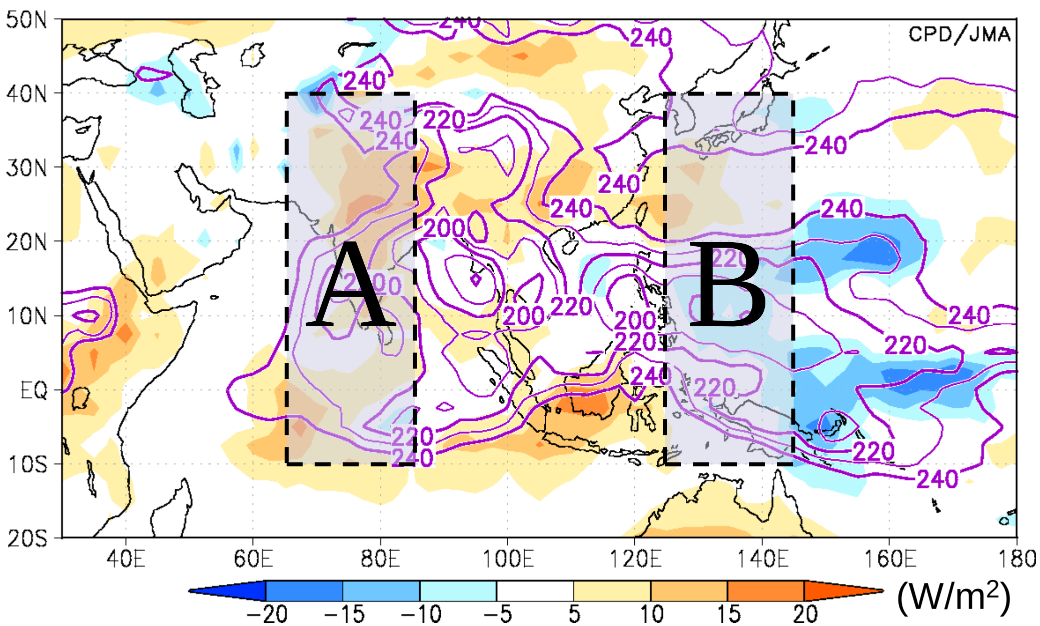
- Arctic Oscillation (AO)
  - AO appears as the 1st EOF mode of SLP in the Northern Hemisphere.
  - Featured by negative anomalies in high-latitude and positive ones in mid-latitude (positive AO).
  - Equivalent barotropic structure (annular mode)
- AntArctic Oscillation (AAO) in the Southern Hemisphere



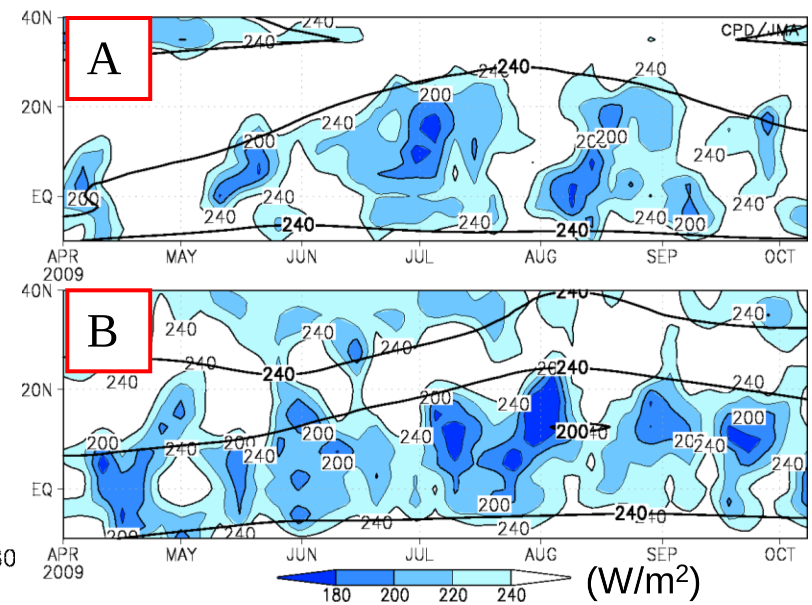
1st EOF mode of SLP anomalies (hPa) poleward of 20ºN in boreal winter

Asian summer monsoon 2009

- Monsoon activities 2009 were suppressed throughout the season except in the West North Pacific Monsoon (WNPM) region.
- Monsoon onset delayed over India.
- The variation of about 30-day period dominated the WNPM region.



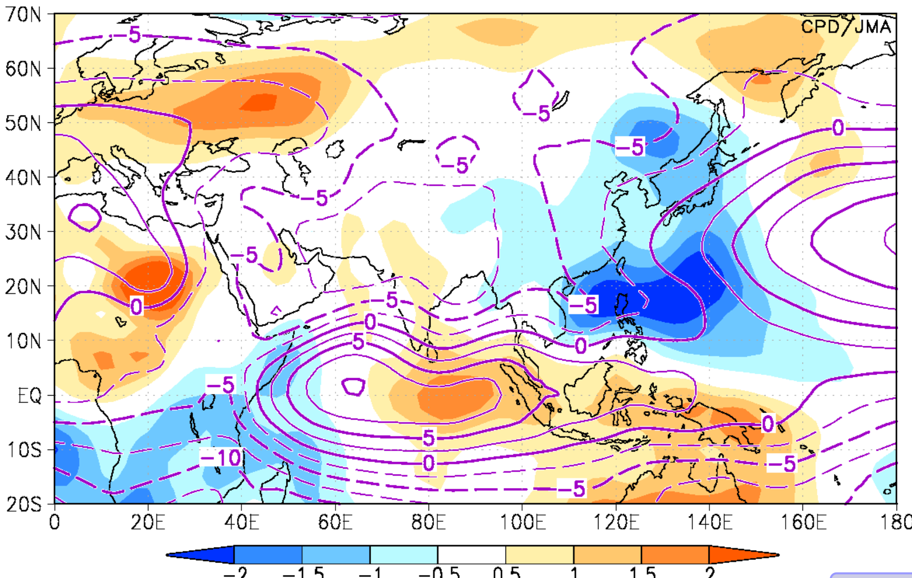
Jun. – Sep. mean OLR (contours, W/m²) and its anomaly (shadings)

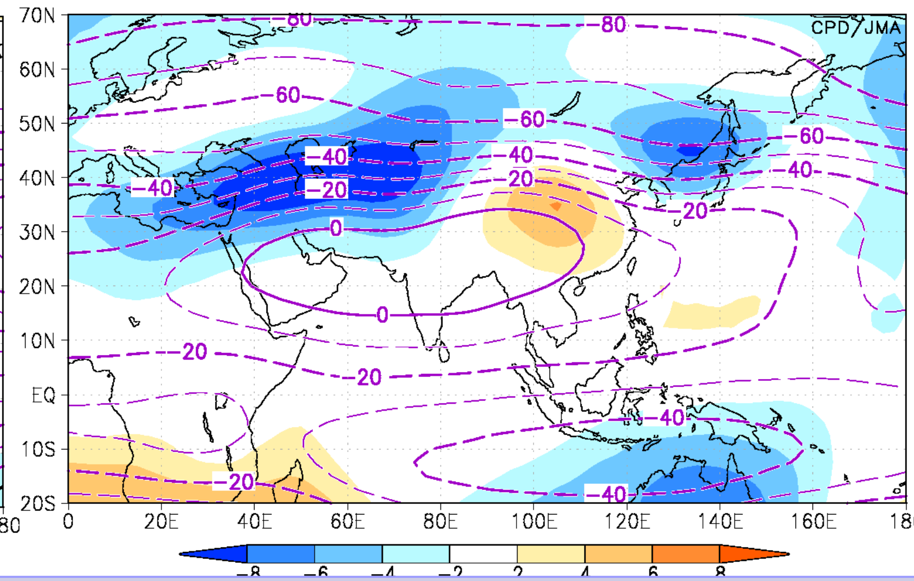


Latitude-time cross section of 5-day mean OLR

Asian summer monsoon 2009

- Monsoon trough was stronger than normal.
- Though the monsoon circulation was stronger than normal over the eastern Indian Ocean, its influence on India was weak.
- The Tibetan High shifted southward from Arabian Peninsula to India.
  - Corresponding to the suppressed convections over India





Jun. – Sep. mean 850-hPa Stream functior (contours, $\times 10^6 m^2/s$) and its anomaly (shading

Detailed report can be read in TCC News No.18.

URL: http://ds.data.jma.go.jp/tcc/tcc/news/tccnews18.pdf

Helmholtz's theorem

- Velocity is decomposed into a "rotational part" and a "divergent part".

$$\vec{v} = \vec{v}_{\psi} + \vec{v}_{\chi}$$

< Rotational wind >

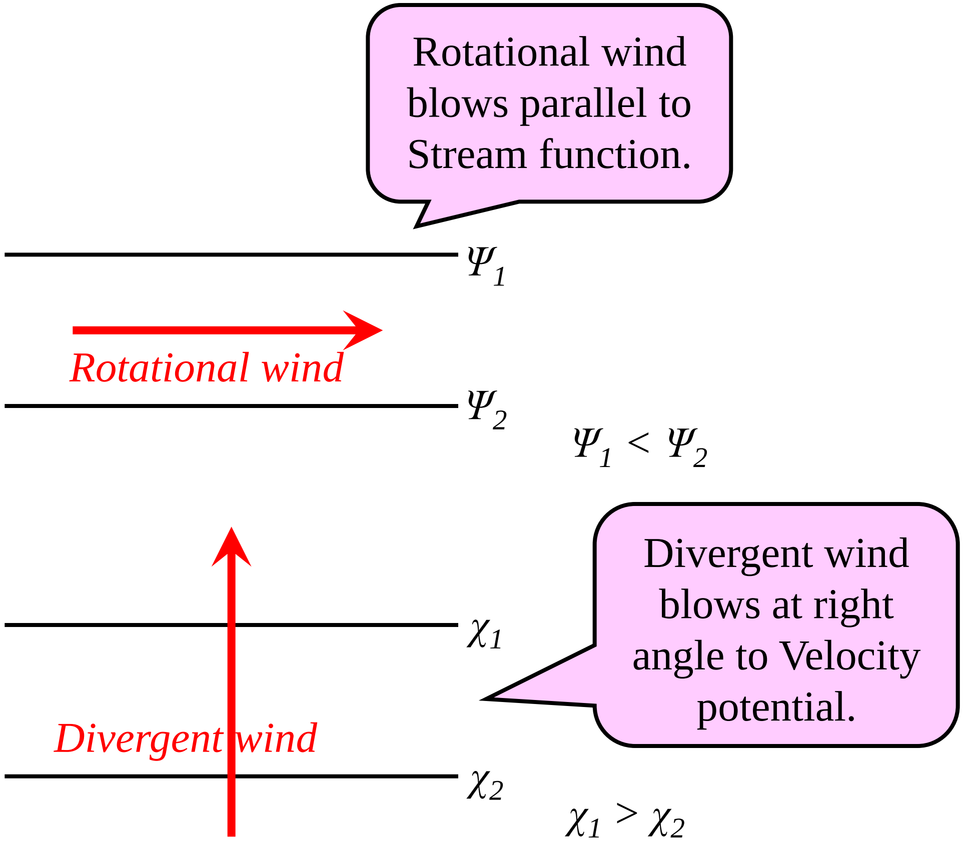
$$u_{\psi} = -\frac{\partial \psi}{\partial y}, v_{\psi} = \frac{\partial \psi}{\partial x}$$

Ψ: Stream function

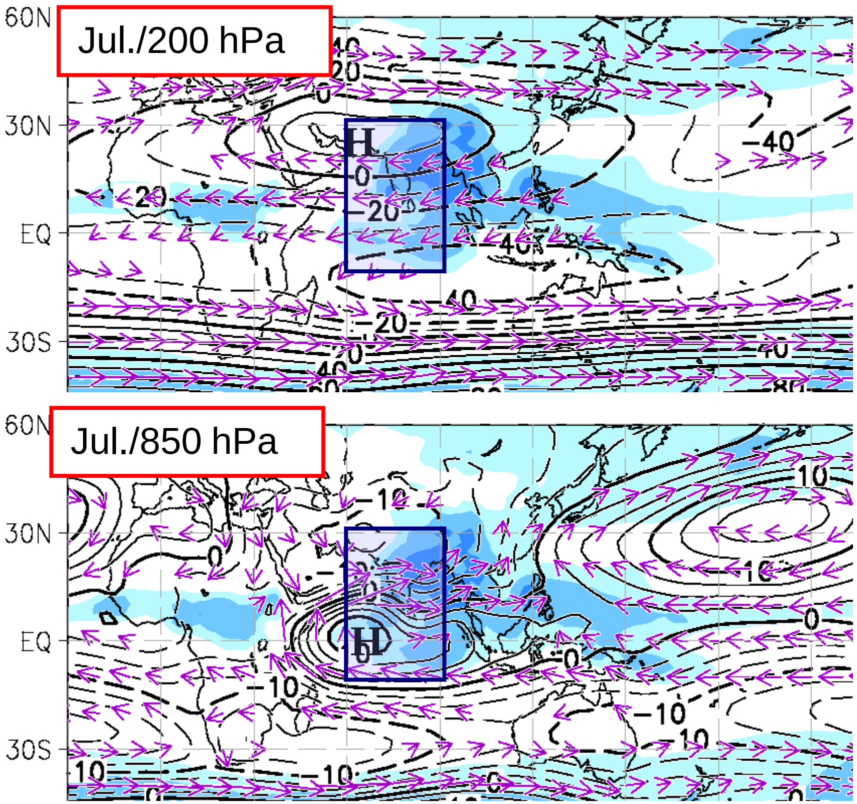
< Divergent wind >

$$u_{\chi} = \frac{\partial \chi}{\partial x}, v_{\chi} = \frac{\partial \chi}{\partial y}$$

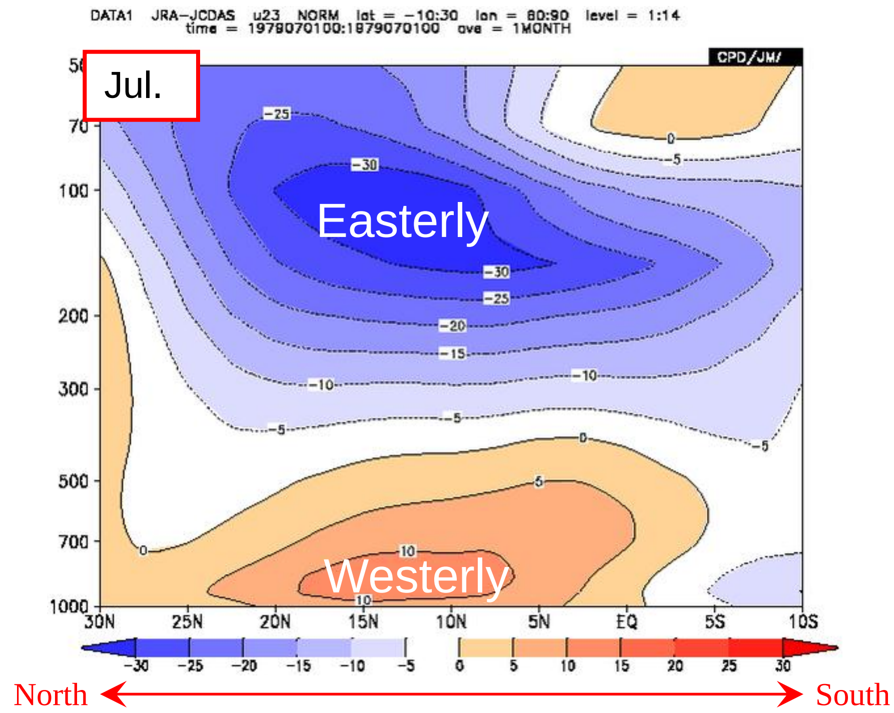
χ: Velocity potential



Critical level of Asian summer monsoon



Monthly mean 850- (top) & 200- (bottom) hPa Stream function (contours, ×$10^6 m^2/s$), OLR (shadings, W/m^2) and wind (vectors, m/s) (1979 – 2004 mean)



Latitude-height cross section of Monthly mean zonal wind (m/s) (60ºE – 90ºE mean) (1979 – 2004 mean)

References

Ishii, M., A. Shouji, S. Sugimoto and T. Matsumoto, 2005: Objective Analyses of Sea-Surface Temperature and Marine Meteorological Variables for the 20th Century using ICOADS and the Kobe Collection. *Int. J. Climatol*., **25**, 865 – 879.

Madden, R. A. and P. R. Julian, 1972: Description of global scale circulation cells in the tropics with a 40 – 50 day period. *J. Atmos. Sci*., **29**, 1109 – 1123.

Onogi, K., J. Tsutsui, H. Koide, M. Sakamoto, S. Kobayashi, H. Hatsushika, T. Matsumoto, N. Yamazaki, H. Kamahori, K. Takahashi, S. Kadokura, K. Wada, K. Kato, R. Oyama, T. Ose, N. Mannoji and R. Taira, 2007: The JRA-25 Reanalysis. *J. Meteor. Soc. Japan*, **85**, 369 – 432.

Trenberth, K.E. et. al., 1998: Progress during TOGA in understanding and modeling global teleconnections associated with tropical sea surface temperatures. *J. Geophys. Res*., **103**, 14291 – 14324.

Wallace, J. M., and D. S. Gutzler, 1981: Teleconnections in the Geopotential Height Field during the Northern Hemisphere Winter. *Mon. Wea. Rev*., **109**, 784 – 812.

Wheeler, M., and H. Hendon, 2004: An All-Season Real-Time Multivariate MJO Index: Development of an Index for Monitoring and Prediction. *Mon. Wea. Rev*., **132**, 197 – 1932.