Impacts of Tropical SST Variability on the Global Climate

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  - Stream function and velocity potential
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- El Niño Southern Oscillation (ENSO)
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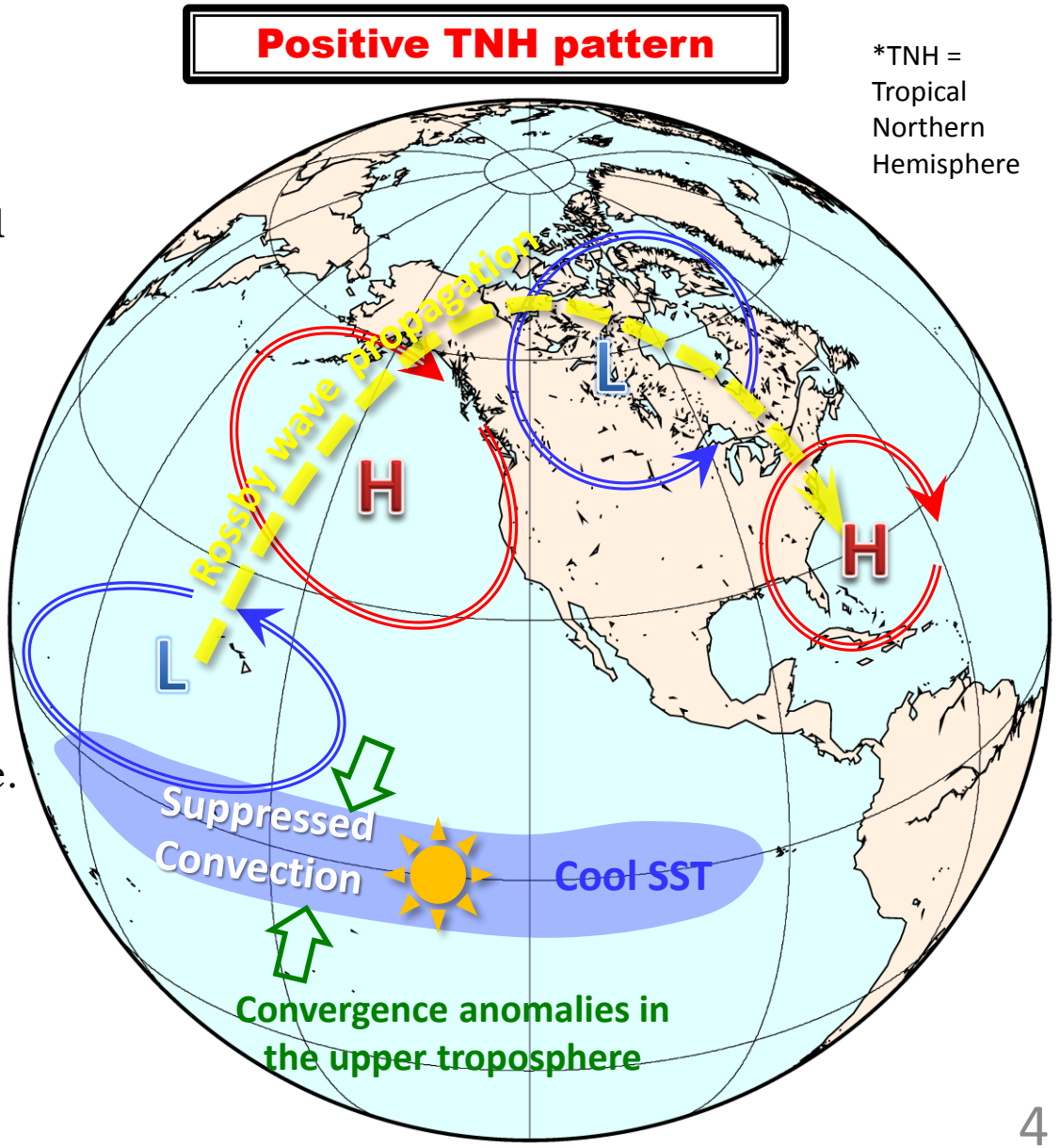
- Indian Ocean Basin Wide
- ENSO/IOBW-related supplemental materials available on the TCC website

Introduction

- Sea surface temperature (SST) variability in the tropics can significantly impact on the global climate through atmospheric circulation.
- It is well known that El Niño/La Niña events (ENSO), which are identified by SST fluctuations from the central to the eastern equatorial Pacific, impact on the atmospheric circulation and induce extreme climate events in the world.
- To understand the current conditions and future predictions of the atmospheric circulation, it is important to know primary modes of variability in the atmosphere associated with SST variability, especially in the tropics.
- In this session, typical impacts of tropical SST variability on the global climate will be introduced, such as (1) NINO.3 SST and (2) tropical Indian Ocean (IOBW).

Teleconnection

- A primary mode of variability is closely related to an important concept of ***Teleconnection***.
- Teleconnection refers to a causal connection of the atmospheric circulation anomalies between remote regions.
- Teleconnection is possible because ***Rossby waves*** (alternate cyclonic and anticyclonic anomalies in the right figure) transport anomalous energy and momentum over a great distance.
- The source of Rossby waves can be often traced back to convection anomalies in the tropics, though this is not always true.



Stream function and velocity potential

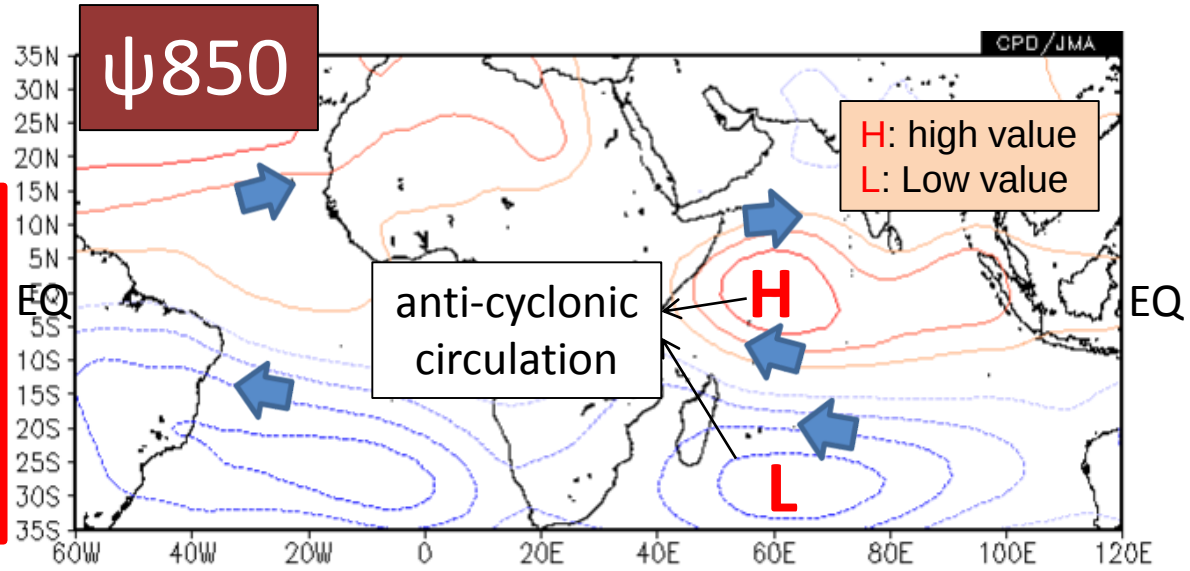
- Decomposing wind into a rotational part and a divergent part (stream function and velocity potential) is useful to analyze atmospheric circulation.

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

< Rotational wind >

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

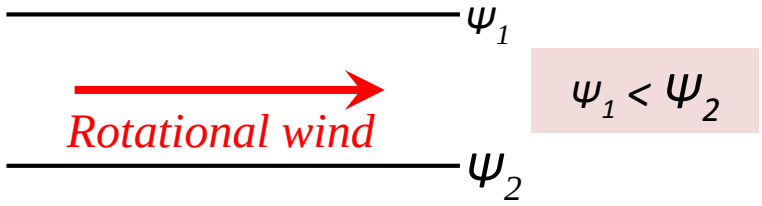
Ψ: Stream function



< Divergent wind >

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

χ: Velocity potential



Rotational wind blows parallel to contours of stream function, with low values of stream function to the left, regardless of the hemisphere.

Stream function and velocity potential (cont.)

- Decomposing wind into a rotational part and a divergent part (stream function and velocity potential) is useful to analyze atmospheric circulation.

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

< **Rotational** wind >

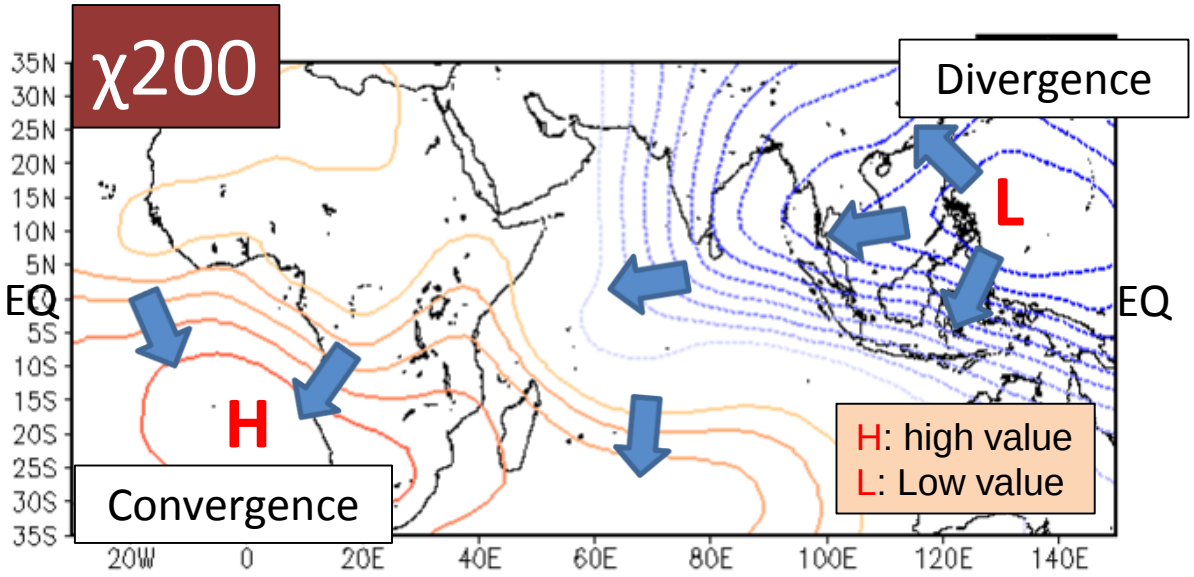
$$u_\psi = -\frac{\partial \psi}{\partial y}, v_\psi = \frac{\partial \psi}{\partial x}$$

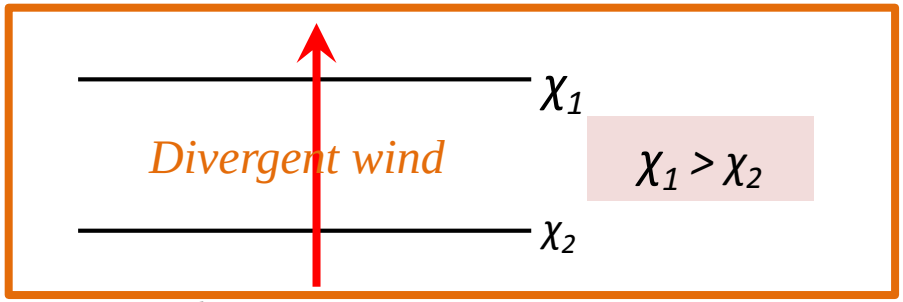
Ψ: Stream function

< **Divergent** wind >

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

χ: Velocity potential





Divergent wind blows across contours of velocity potential, from areas of low to high velocity potential, regardless of the hemisphere.

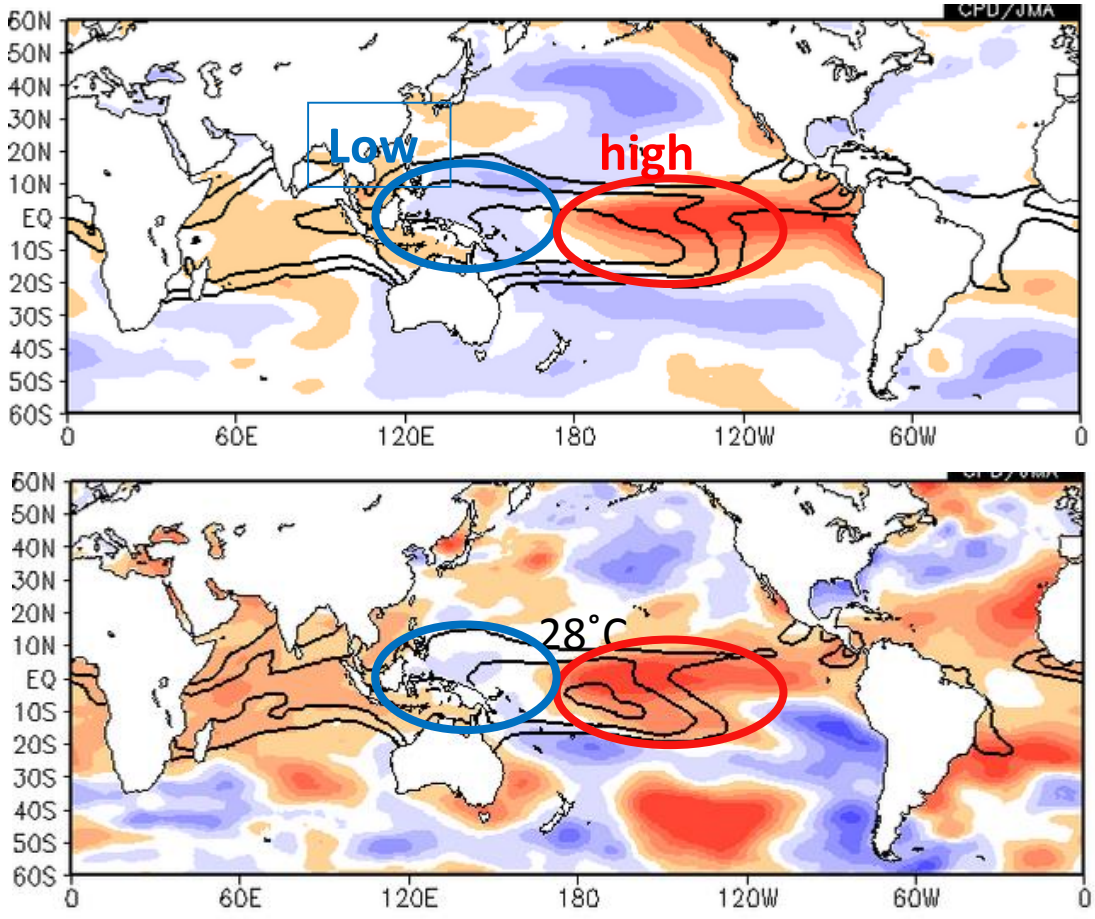
Composite analysis

- 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.

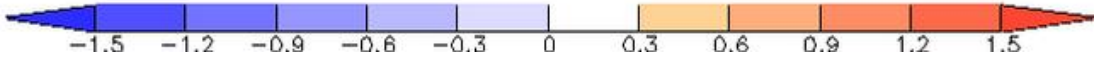
SST Composite Map in El Niño Phase (DJF)

Contours: analysis, Shadings: anomaly,
Statistical period: 1979/80 – 2008/09
(Composite years: (6 years)
82/83, 86/87, 87/88, 91/92, 97/98, 02/03)

SST for DJF 2009/10



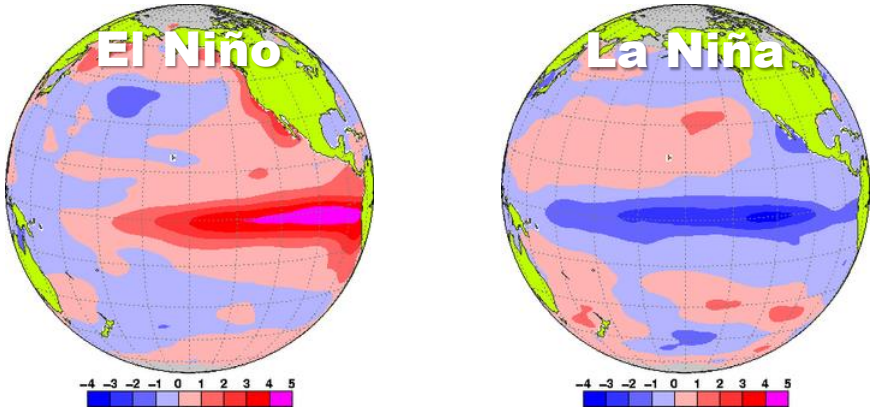
3-month mean SST and anomalies (˚C)



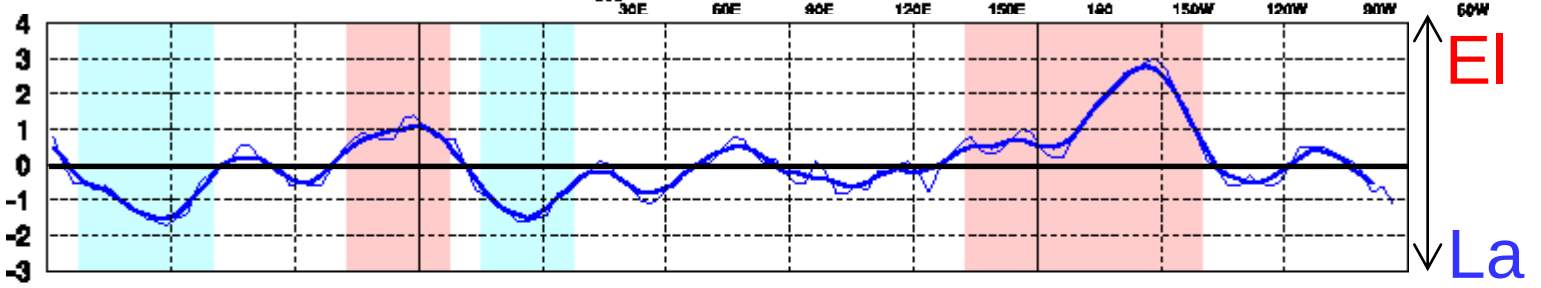
El Niño Southern Oscillation (ENSO)

- The most dominant mode of variability in Earth's climate system.

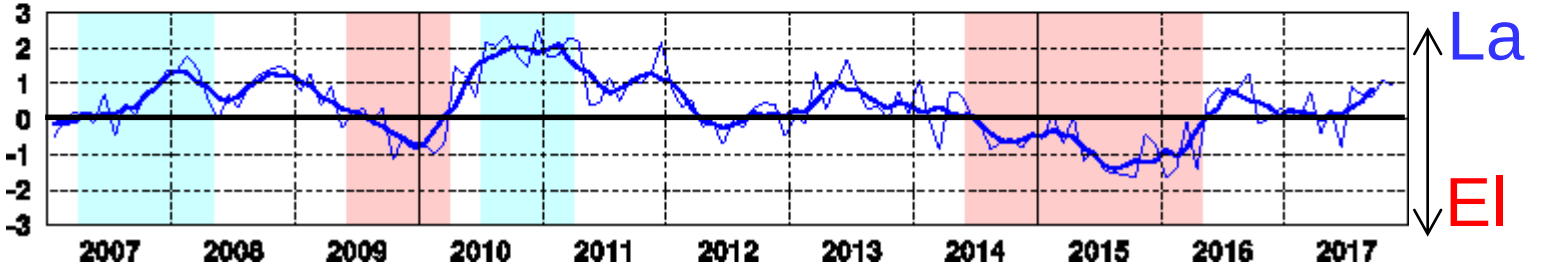
- SSTs in the central to eastern Pacific swing back and forth between a positive (El Niño) and negative (La Niña) phase on a cycle of 2-7 years.



NINO.3 index



Southern Oscillation Index



The Southern Oscillation Index is defined as

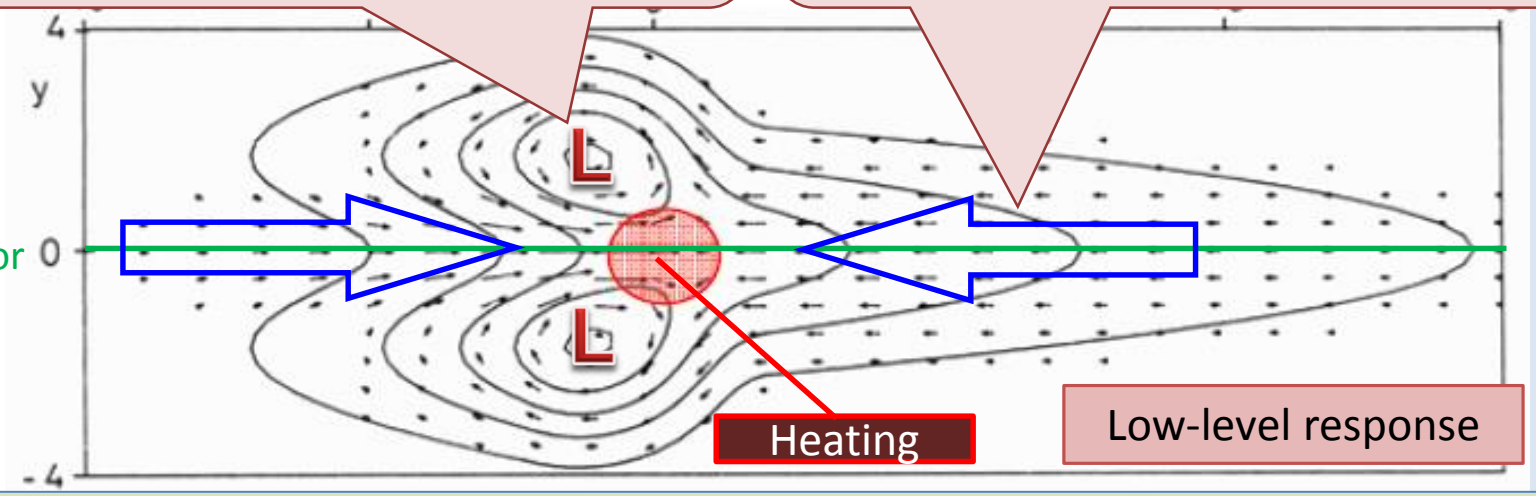
SOI = X/ SD(X), where X = ANM(Ps(Tahiti))/ SD(Ps(Tahiti)) - ANM(Ps(Darwin))/ SD(Ps(Darwin))

Matsuno-Gill pattern

- Gill (1980) elucidated some basic features of the response of the tropical atmosphere to diabatic heating (related to convective activity).

A pair of cyclonic circulation straddling the equator on the western side of the heating (equatorial Rossby wave).

Low pressure and easterly winds along the equator east of the heating (equatorial Kelvin wave).



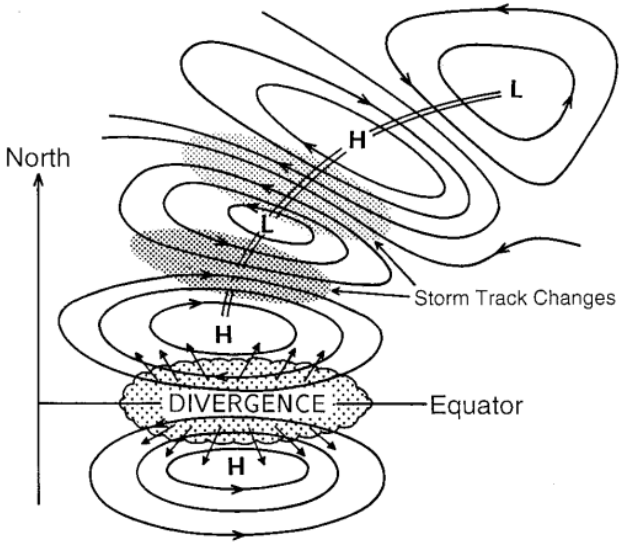
Atmospheric response in the lower troposphere to the heating symmetric about the equator

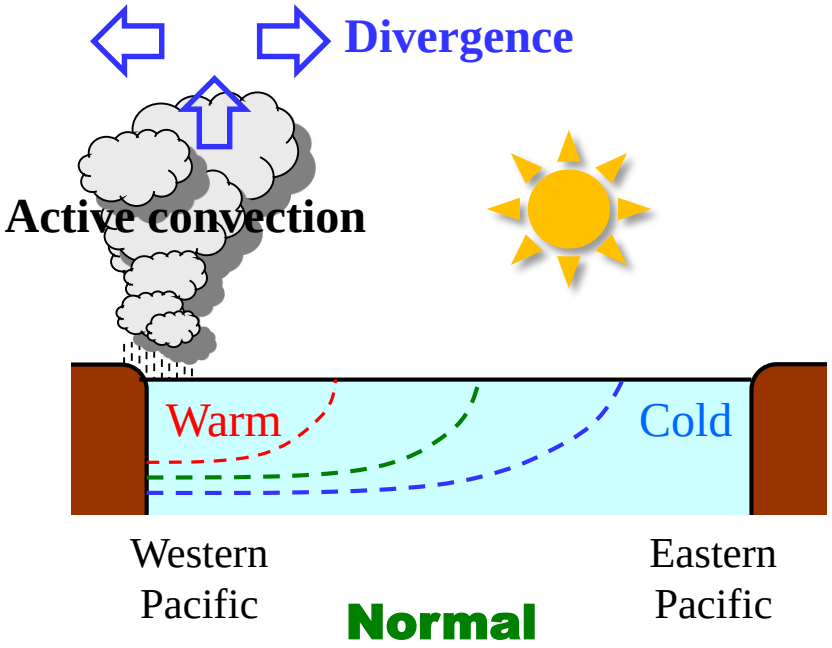
Contours indicate perturbation pressure, and vectors denote velocity field.
Red circle indicates the position of the heating. (Source: Gill 1980)

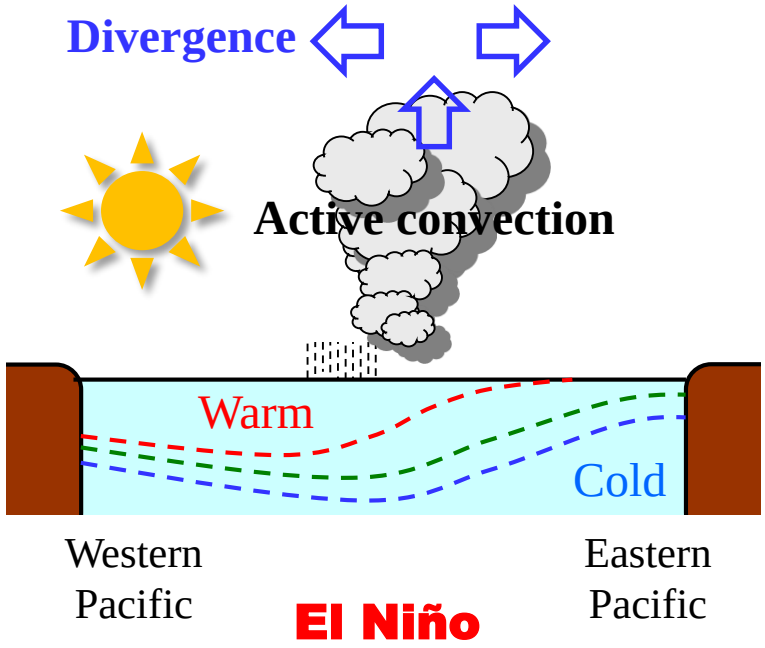
Upper-level response shows the reverse of the low-level response.

El Niño Southern Oscillation

- During an El Niño (La Niña) episode, a significant increase (decrease) in SST over the central to eastern equatorial Pacific is observed.
- The warmer/cooler SSTs lead to convection anomalies in the tropical Pacific.
- These convection anomalies generate Rossby waves, which propagate over a large distance and influence the global atmosphere (teleconnection).



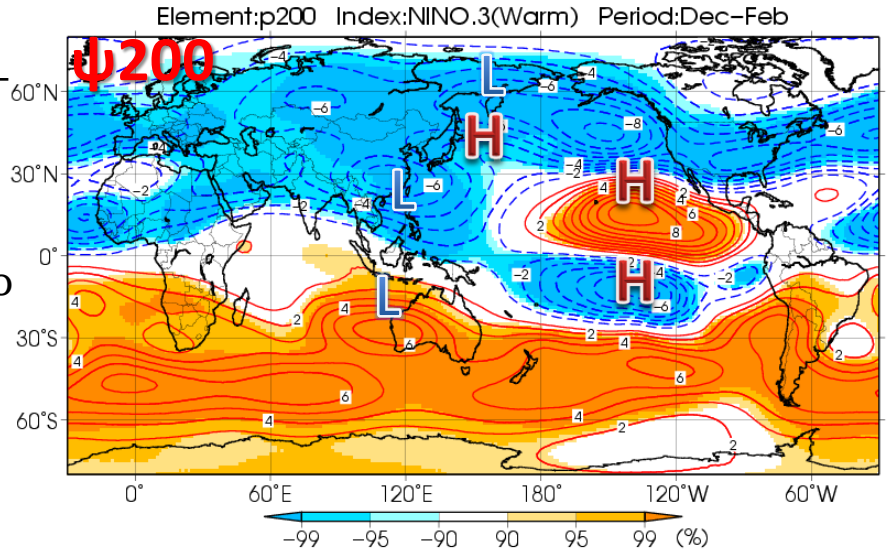


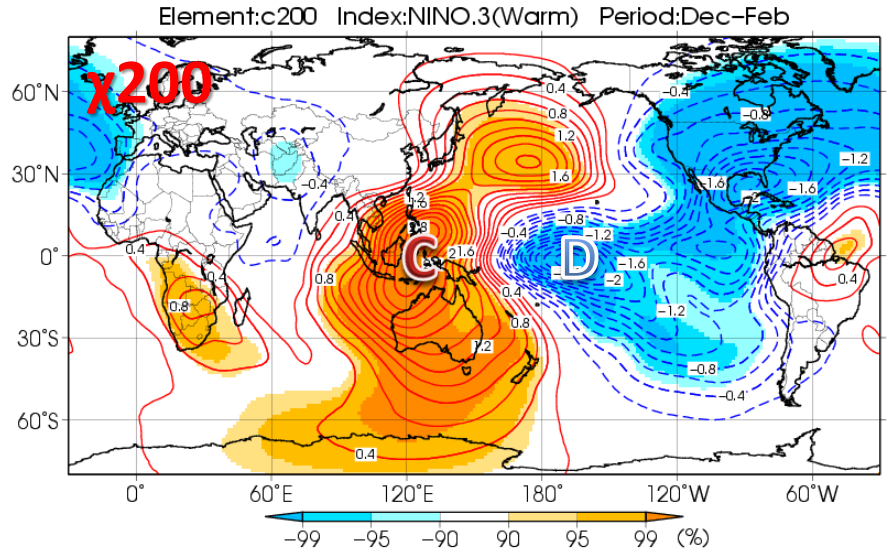


ENSO and atmospheric circulation (El Niño DJF)

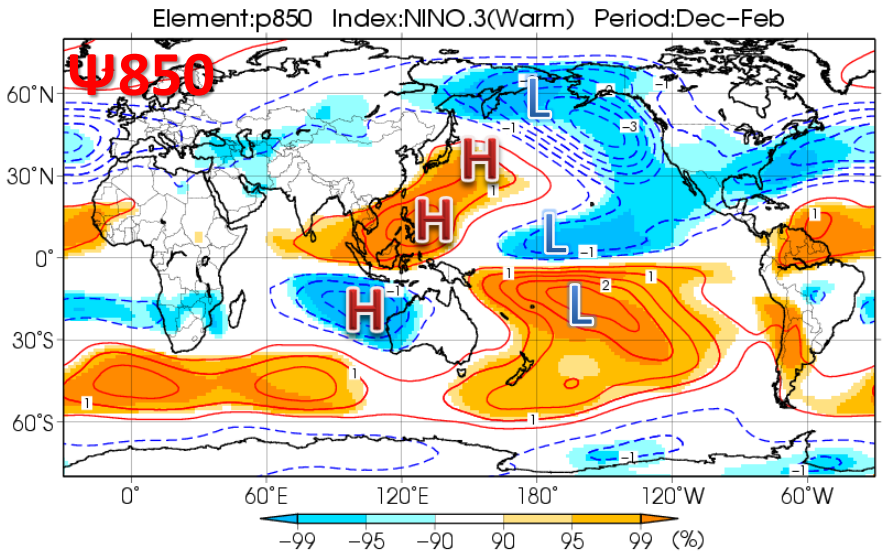
In December to February of El Niño years,

- In the upper troposphere, cyclonic and anti-cyclonic anomalies develop in the western and eastern Pacific, respectively.
- A Rossby wave train extends from cyclonic anomalies centered over South China Sea to the North Pacific.
- In the lower troposphere, anti-cyclonic and cyclonic anomalies develop in the western and eastern Pacific, respectively.





Composite **velocity potential anomalies** for DJF during past El Niño events. "C" and "D" stand for convergence and divergence anomalies, respectively.

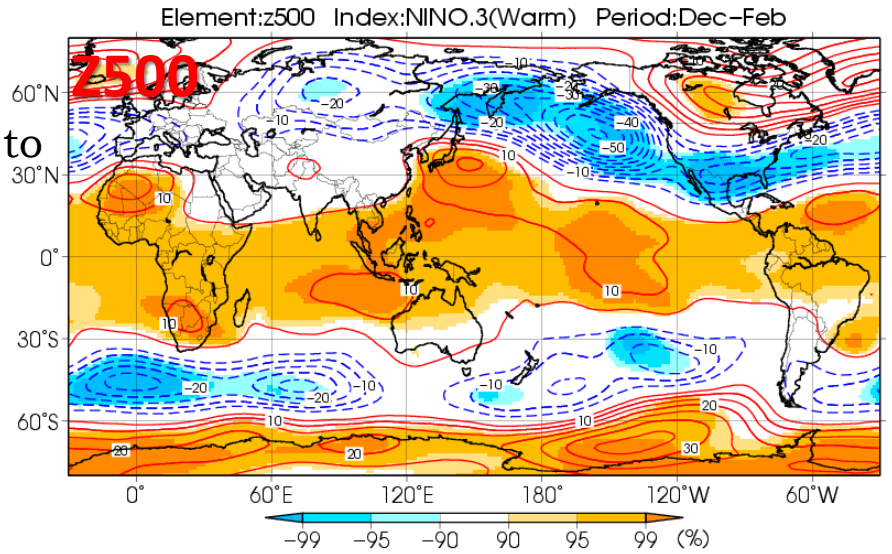


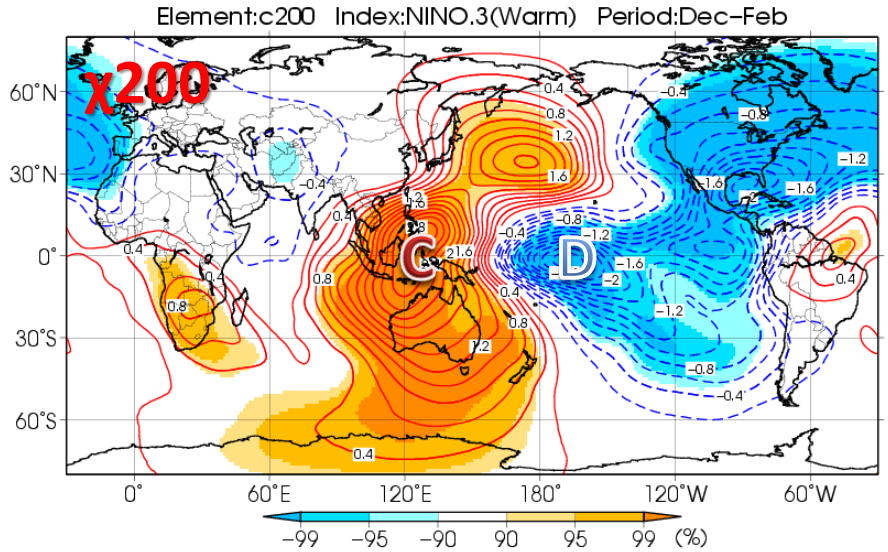
Composite **stream function anomalies** at 200hPa (top panel) and 850hPa (bottom panel) for DJF during past El Niño events

ENSO and atmospheric circulation (El Niño DJF)

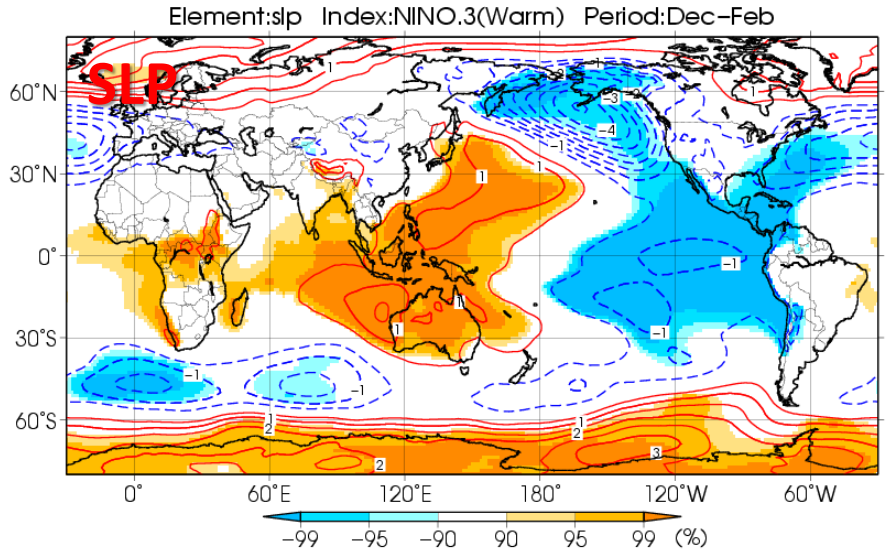
In December to February of El Niño years,

- In the 500hPa height field, positive anomalies extend in the global tropics and to the southeast of Japan, and negative anomalies in the northern North Pacific.
- In the SLP field, positive anomalies extend from the eastern Indian Ocean to the western Pacific and negative anomalies in the eastern Pacific.





Composite **velocity potential anomalies** for DJF during past El Niño events. "C" and "D" stand for convergence and divergence anomalies, respectively.

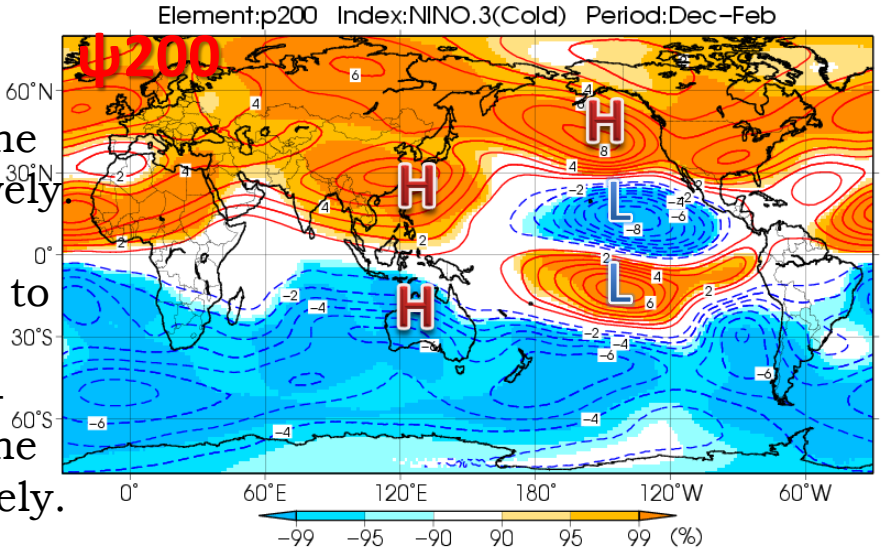


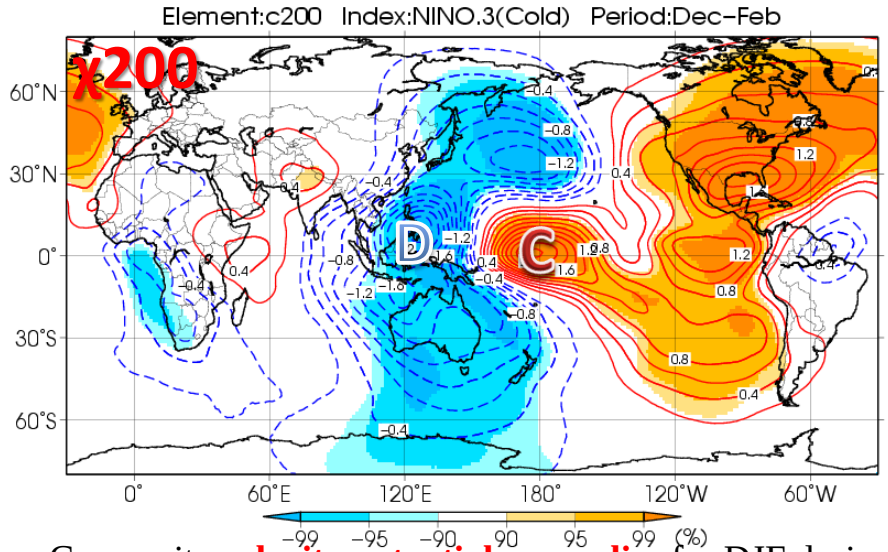
Composite anomalies of **500hPa height** (top) and **SLP** (bottom) for DJF during past El Niño events

ENSO and atmospheric circulation (La Niña DJF)

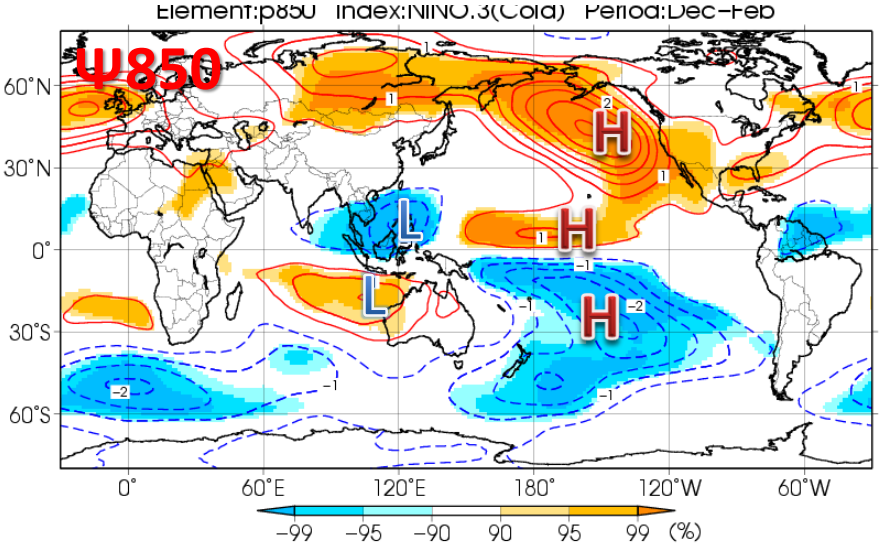
In December to February of La Niña years,

- In the upper troposphere, anticyclonic and cyclonic anomalies develop over the Maritime Continent and the eastern Pacific, respectively.
- A Rossby wave train extends from cyclonic anomalies centered over the eastern Pacific to North America, resembling positive TNH.
- In the lower troposphere, cyclonic and anti-cyclonic anomalies develop over the Maritime Continent and the central Pacific, respectively.





Composite **velocity potential anomalies** for DJF during past La Niña events. "C" and "D" stand for convergence and divergence anomalies, respectively.

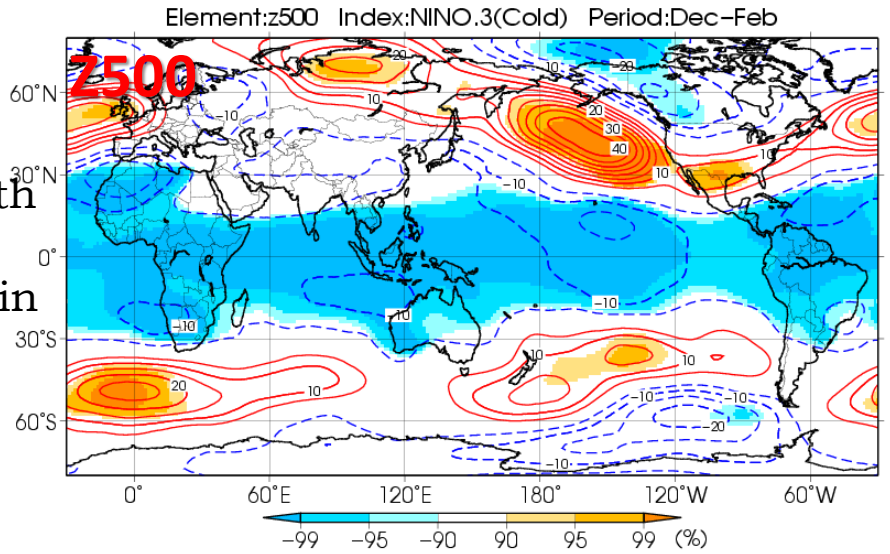


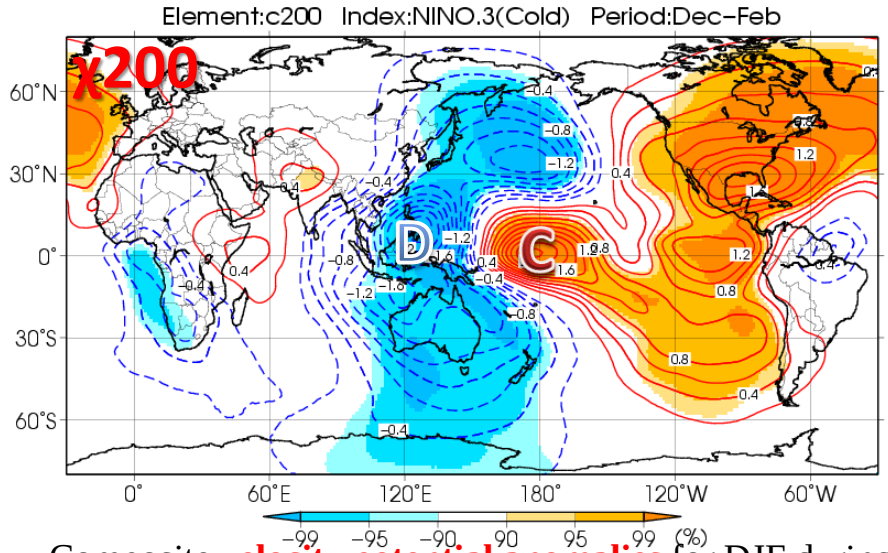
Composite **stream function anomalies** at 200hPa (top panel) and 850hPa (bottom panel) for DJF during past La Niña events

ENSO and atmospheric circulation (La Niña DJF)

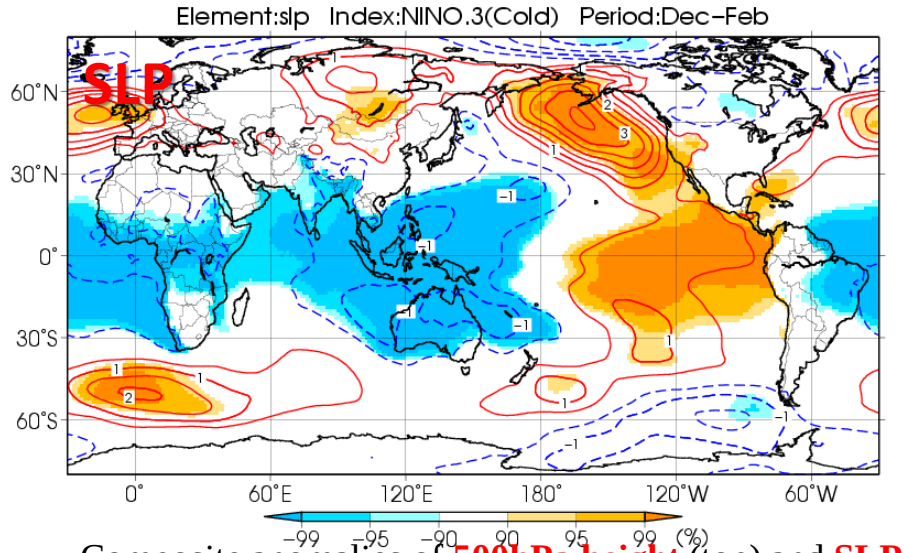
In December to February of La Niña years,

- In the 500hPa height field, negative anomalies extend in the global tropics and positive anomalies in the northeastern North Pacific.
- In the SLP field, positive anomalies extend in the eastern Pacific, and negative anomalies in the Indian Ocean to the western Pacific.





Composite **velocity potential anomalies** for DJF during past La Niña events. "C" and "D" stand for convergence and divergence anomalies, respectively.

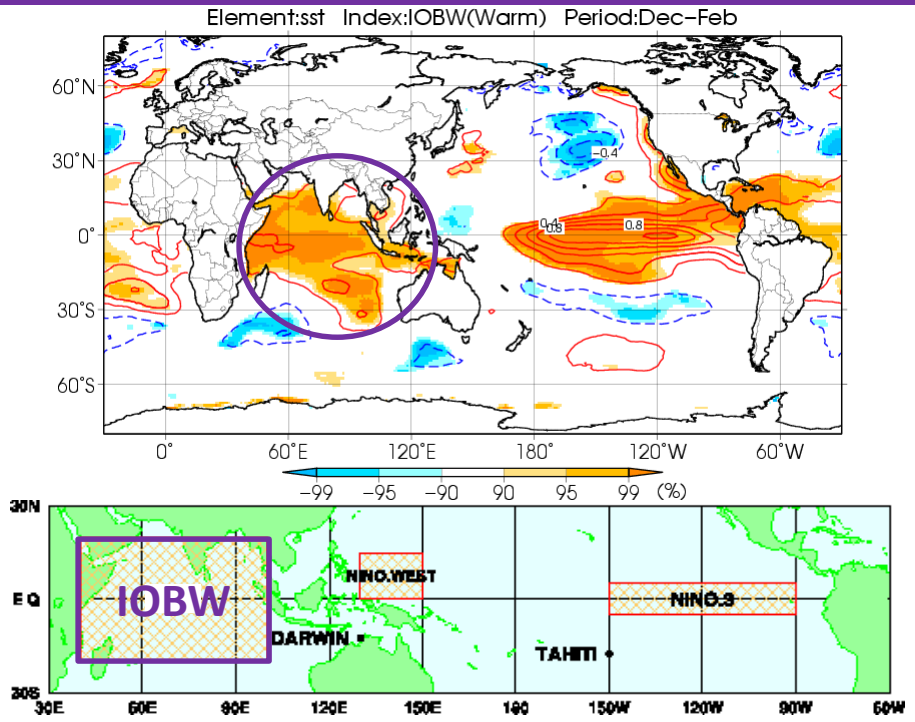


Composite anomalies of **500hPa height** (top) and **SLP** (bottom) for DJF during past La Niña events

Indian Ocean Basin Wide

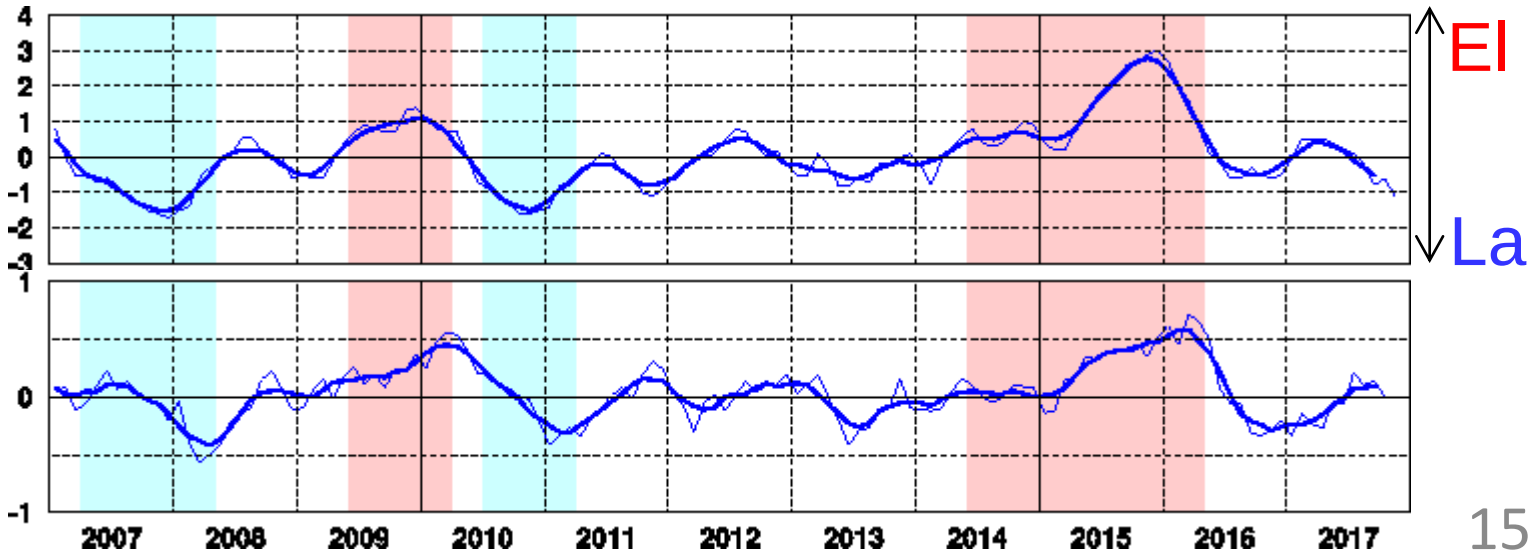
- As in the Pacific, SSTs in the Indian Ocean are known to fluctuate between a positive and negative phase basin-wide.

- SSTs in the tropical Indian Ocean (IOBW; Indian Ocean Basin Wide) region tends to follow in the wake of ENSO with a delay of around 3 months.



NINO.3 index

IOBW

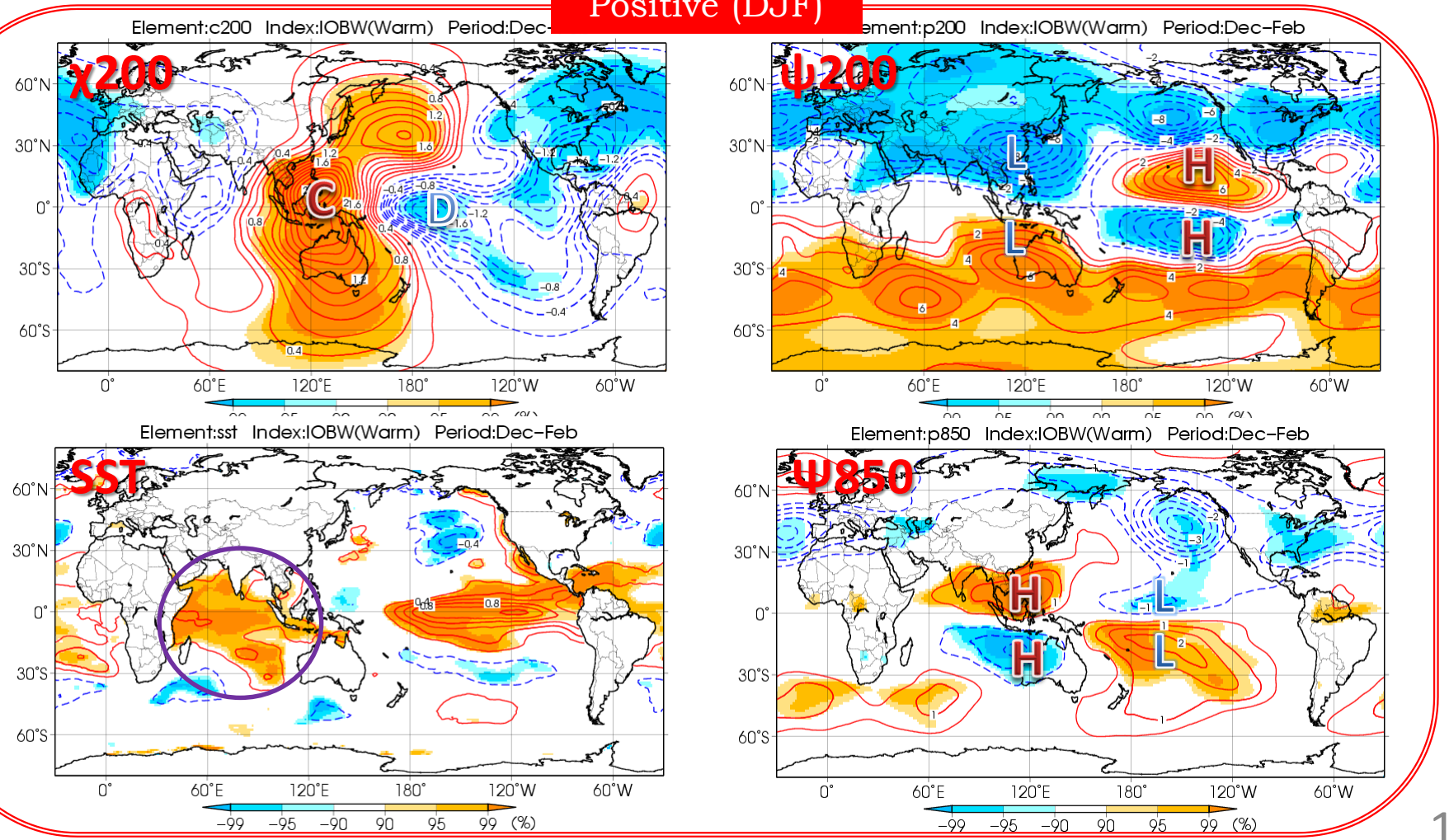


Indian Ocean Basin Wide

In December to February of positive IOBW years,

- In the upper troposphere, cyclonic and anti-cyclonic anomalies develop in the western and eastern Pacific, respectively. In the lower troposphere, anti-cyclonic and cyclonic anomalies develop over the Maritime Continent and the central Pacific, respectively.

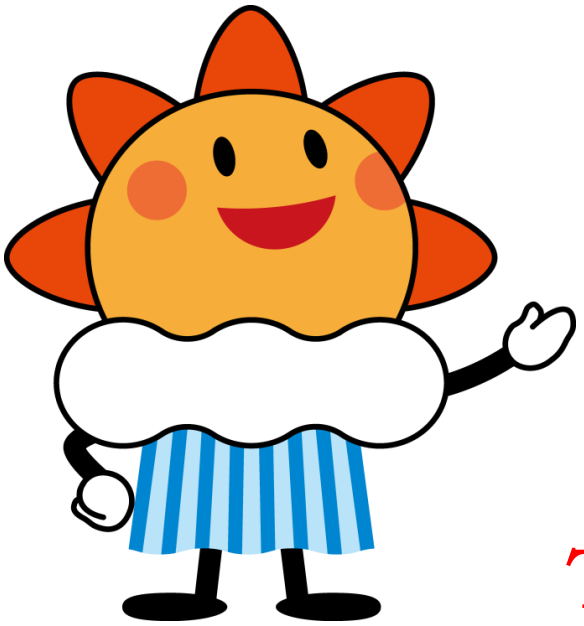
Positive (DJF)



ENSO/IOBW-related supplemental materials

- More detailed composite maps of global circulation anomalies associated with ENSO and IOBW are available at the TCC web site. Please visit
  http://ds.data.jma.go.jp/tcc/tcc/products/clisys/enso_statistics/index.html

  or alternatively, it might be much easier to google:



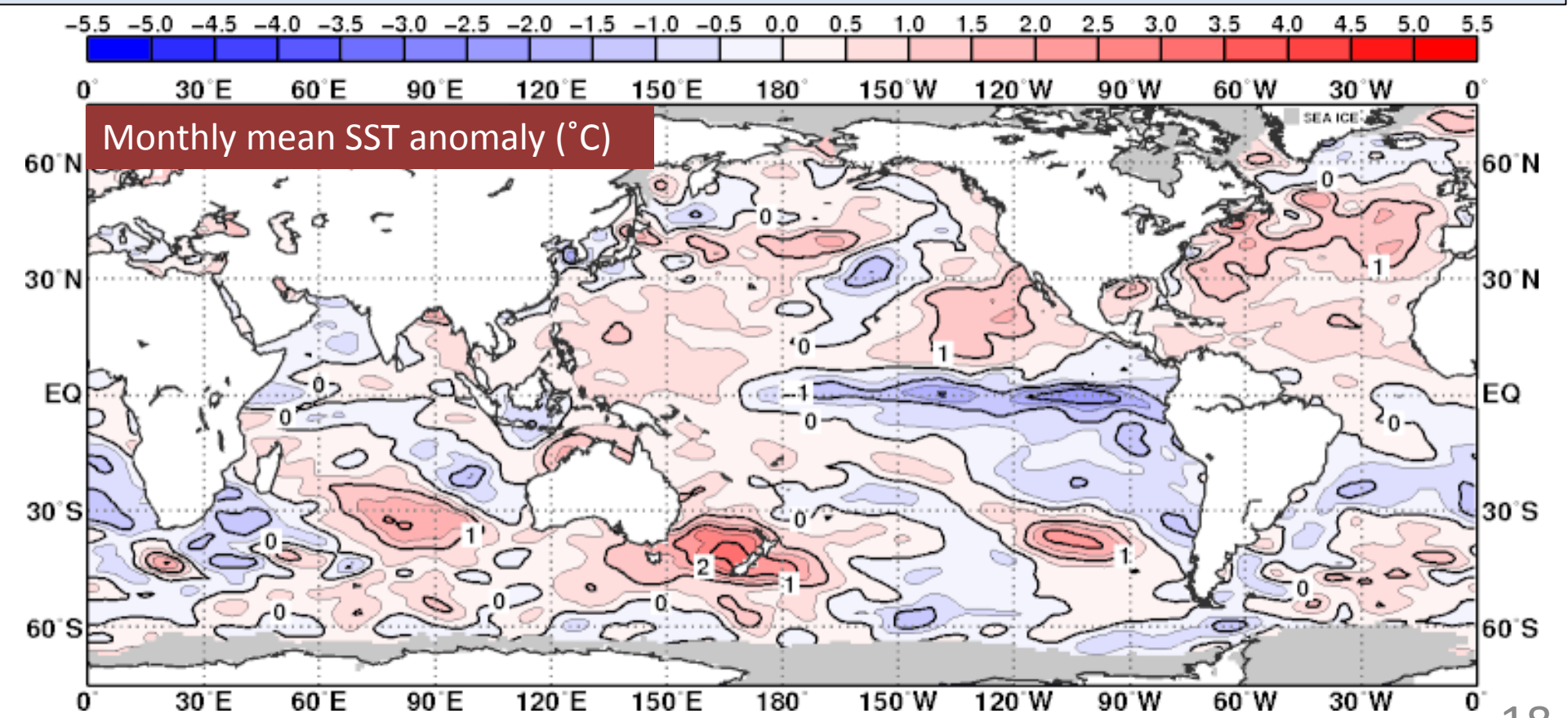
TCC composite map

search

Thank you for your attention.

<December 2017> Sea Surface Temperature (SST)

- In the equatorial Pacific, remarkably positive SST anomalies were observed in the western part and remarkably negative SST anomalies were observed in the eastern part.
- In the North Pacific, remarkably positive SST anomalies were observed in the western tropical region, from the area near 10°N, 155°W to the western coast of Central America, and from the area near 40°N, 175°E to the area near 45°N, 160°W.
- In the Indian Ocean, remarkably positive SST anomalies were observed from the area near Madagascar to the area near 40°S, 100°E, and in the Bay of Bengal, and remarkably negative SST anomalies were observed in the Arabian Sea.

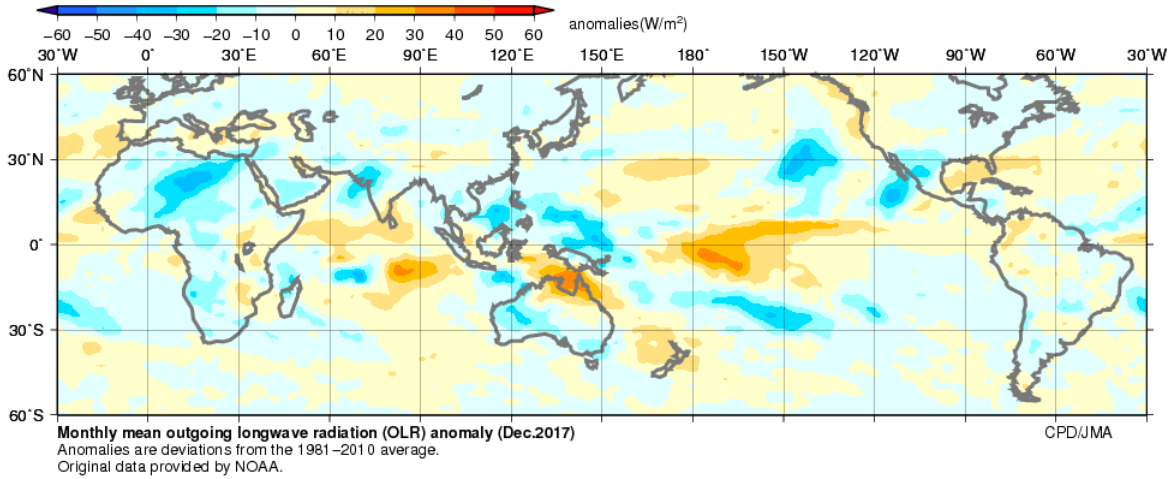


<Monthly mean SST anomalies (Global)> http://ds.data.jma.go.jp/tcc/tcc/products/elnino/ocean/sst-ano-global_tcc.html

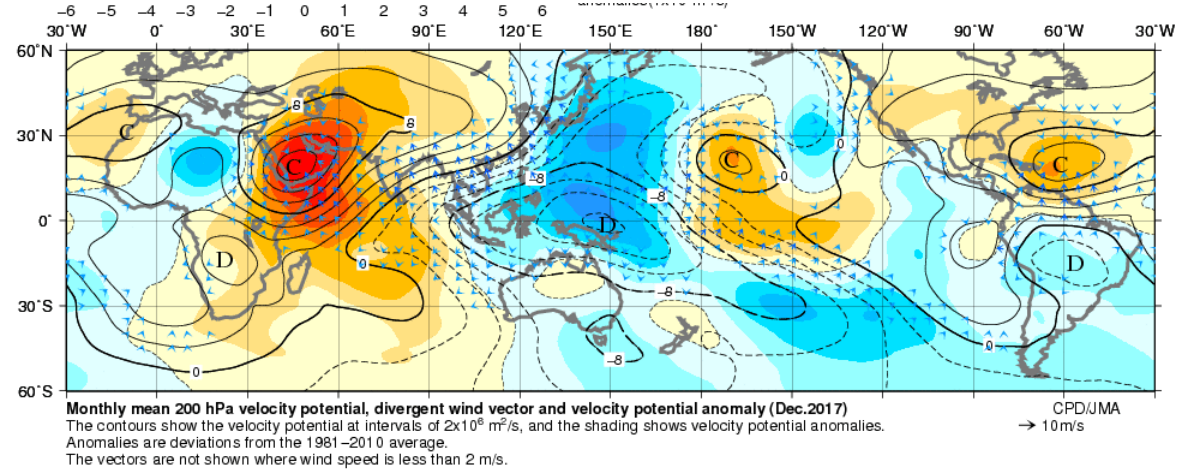
<December 2017> Convective activity in the Tropics

- Convective activity was enhanced from the South China Sea to the seas east of the Philippines and was suppressed over the eastern part of the equatorial Indian Ocean and the central equatorial Pacific.

Monthly mean
OLR anomalies
Shading: OLR anomalies (W/m^2)



Monthly mean
Velocity potential,
Divergent wind vector, and
Velocity potential anomalies
at 200-hPa
Contour: velocity potential (10^{6}m^2/s)
Vector: divergent wind vector (m/s)
Shading: velocity potential anomalies (10^{6}m^2/s)
"D" and "C" indicate the centers of large-scale divergence and convergence anomalies, respectively.



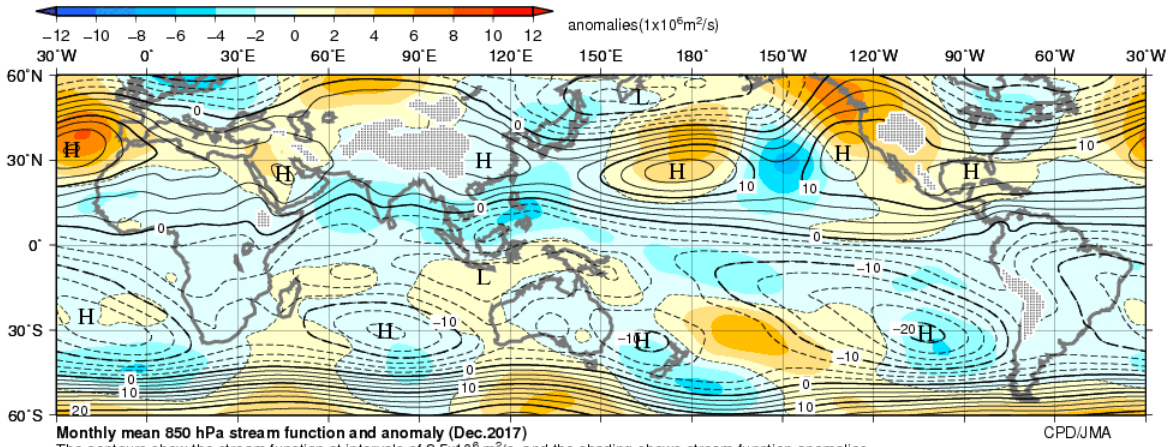
<Monthly Mean Figures> http://ds.data.jma.go.jp/tcc/tcc/products/clisys/figures/db_hist_mon_tcc.html
<Animation Maps (Global Area)> http://ds.data.jma.go.jp/tcc/tcc/products/clisys/anim/anim_tp.html

<December 2017> Low-level Circulation

- In the lower troposphere, cyclonic (anti-cyclonic) circulation anomalies straddling the equator were observed over the Maritime Continent (over the eastern Pacific). Cyclonic circulation anomalies also prevailed over the North Indian Ocean.
- In the sea level pressure field, positive anomalies were observed from the central equatorial Pacific to the eastern Pacific, and negative anomalies were observed from the central North Indian Ocean to the western Pacific, and over the subtropical region of the central South Pacific.

Monthly mean Stream function and its anomalies at 850-hPa

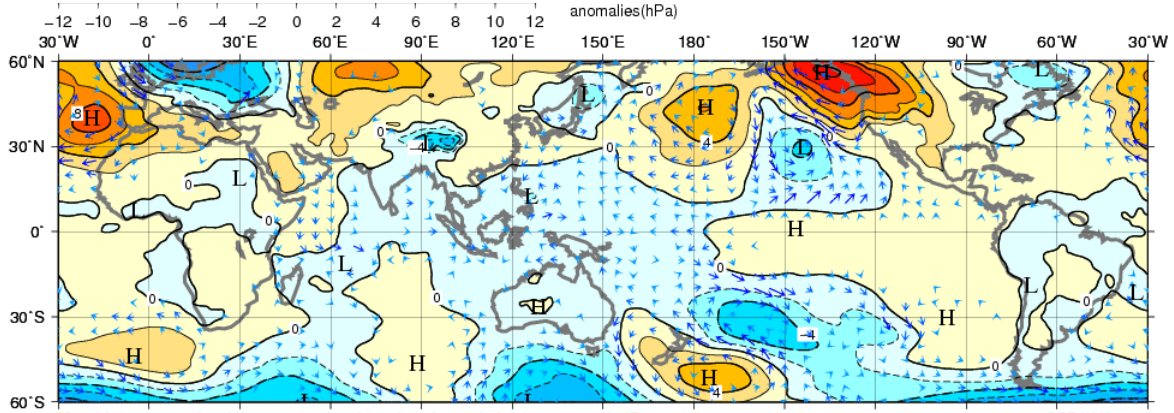
Contour: stream function ($10^6 m^2/s$)
Shading: stream function anomalies ($10^6 m^2/s$)
"H" and "L" indicate the centers of anti-cyclonic and cyclonic circulations, respectively.



Monthly mean 850 hPa stream function and anomaly (Dec.2017)
The contours show the stream function at intervals of 2.5×10^6 m^2/s, and the shading shows stream function anomalies.
The hatch patterns indicate areas with altitudes exceeding 1,600 m.
Anomalies are deviations from the 1981–2010 average.

Monthly mean Sea level pressure anomalies and Surface wind vector anomalies

Contour&shading: sea level pressure anomalies (hPa)
Vector: surface wind vector anomalies (m/s)
"H" and "L" indicate the centers of anti-cyclonic and cyclonic anomalies, respectively.



Monthly mean sea level pressure anomaly and surface wind vector anomaly (Dec.2017)
The contours show sea level pressure anomalies at intervals of 2 hPa.
Anomalies are deviations from the 1981–2010 average.
The vectors are not shown where wind speed is less than 1 m/s.

<Monthly Mean Figures> http://ds.data.jma.go.jp/tcc/tcc/products/clisys/figures/db_hist_mon_tcc.html
<Animation Maps (Global Area)> http://ds.data.jma.go.jp/tcc/tcc/products/clisys/anim/anim_tp.html