Primary modes of variability in Earth's climate system

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What is a primary mode of variability?

- On a daily basis, the global atmospheric circulation seems to fluctuate totally at random.

- But a careful statistical analysis reveals a variety of ***preferred circulation patterns*** which emerge on a hemispheric scale.

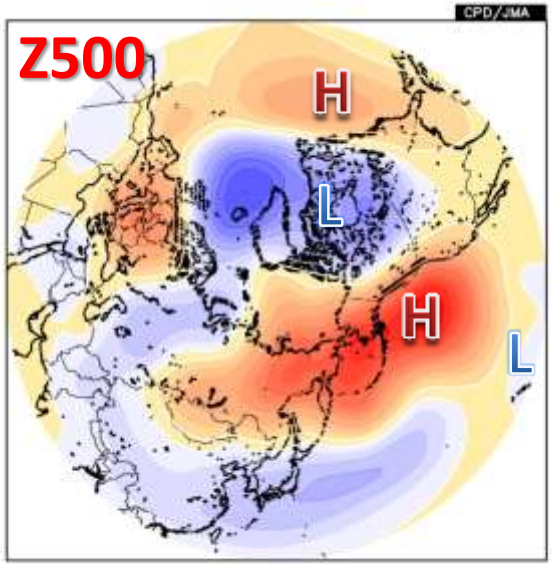
- Because these preferred patterns tend to develop recurrently and last for weeks or longer, climate researchers recognize them as outstanding. Hence called ***primary modes of variability***.

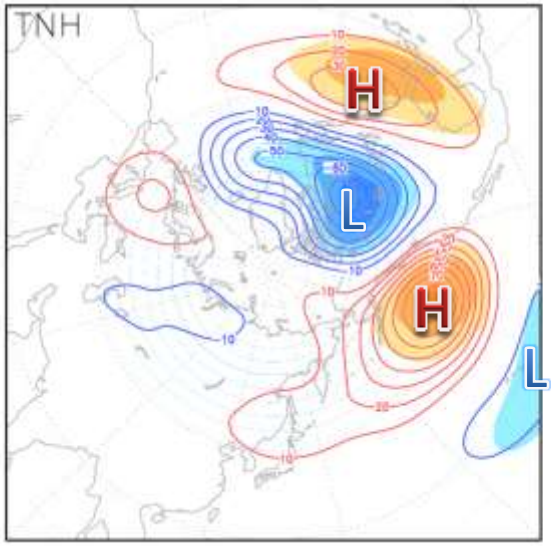
- By exploiting these preferred patterns, we might have a chance of a better climate analysis and prediction skill.

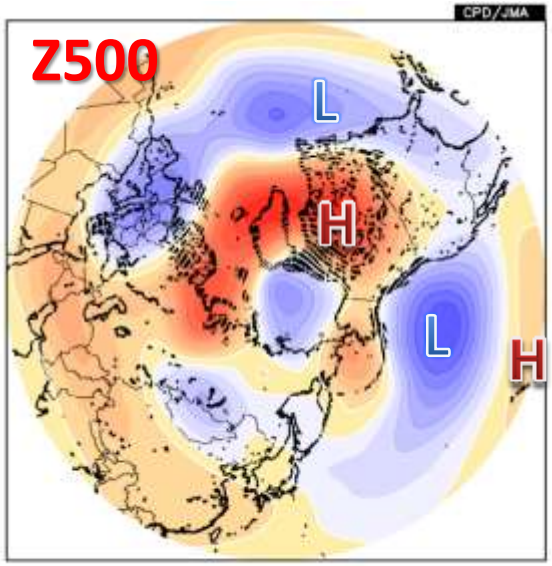
Example of a preferred circulation pattern

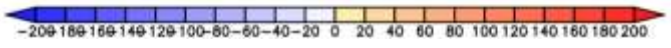
- In the center figure below, cyclonic and anti-cyclonic anomalies alternate from the equatorial Pacific all the way through North America and reach the Atlantic.
- This represents circulation anomalies known as the (positive) ***Tropical-Northern Hemisphere*** (**TNH**) pattern.
- The negative TNH is defined as a pattern of reversed polarity.
- Positive (negative) TNH is associated with dry (wet) conditions in the southwestern US.

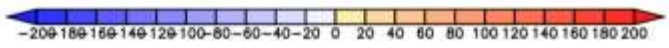
Positive TNH pattern actually seen in Dec. 2013	**Definition** of TNH pattern (500hPa height anomalies)	**Negative** TNH pattern actually seen in Jan. 2010





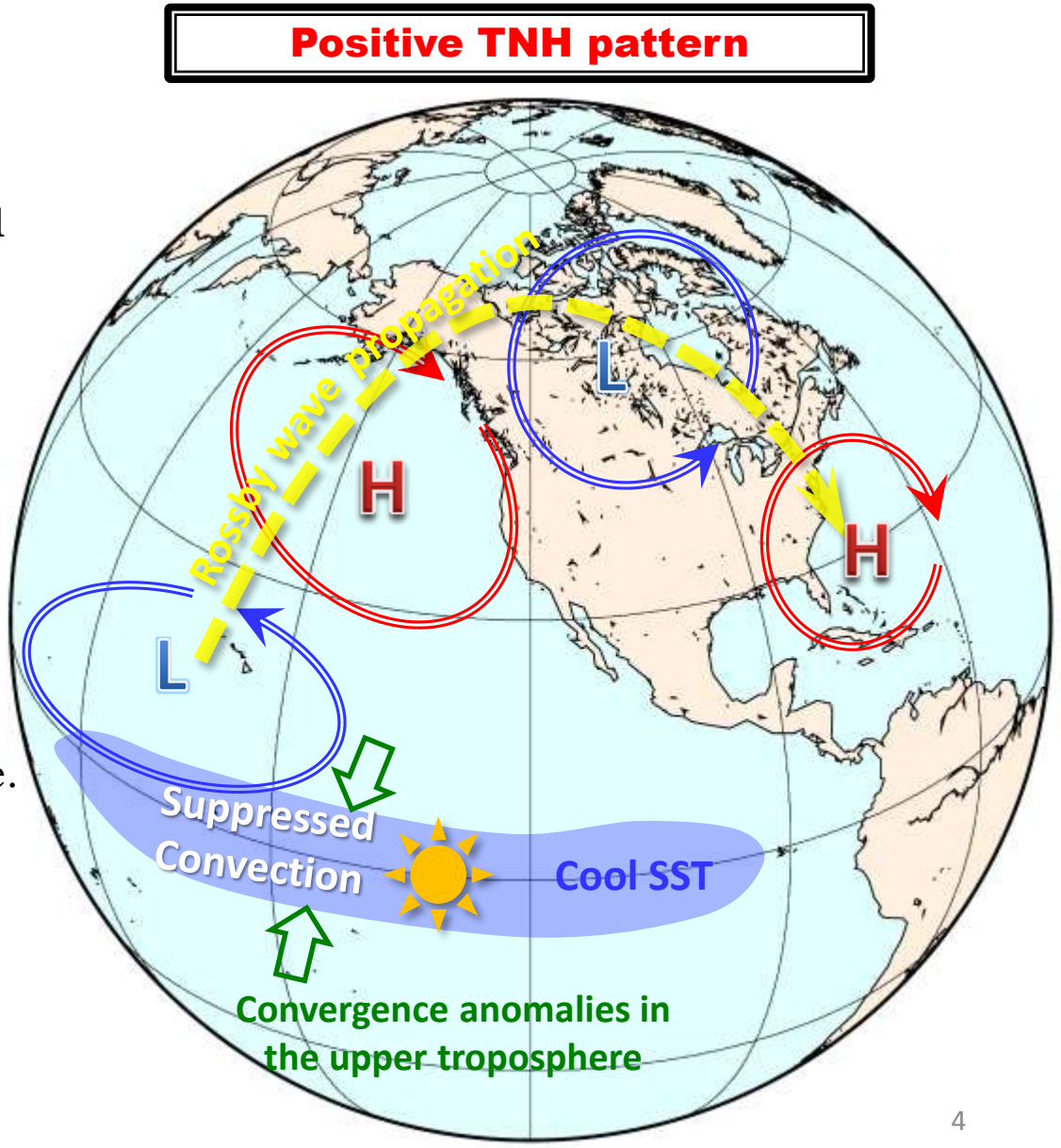






Teleconnection

- 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.



Primary modes of variability

In the following discussion, we are going to focus our attention on four well-known modes of variability below.

These modes are the most relevant to climate variability in the Asia-Pacific region.

1) El Niño Southern Oscillation (ENSO)

2) Indian Ocean Basin Wide (IOBW)

3) Arctic Oscillation (AO)

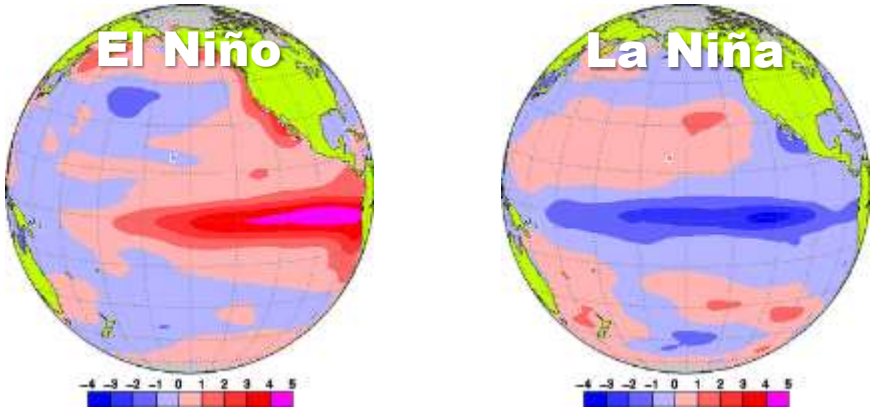
4) Eurasia pattern (EU)

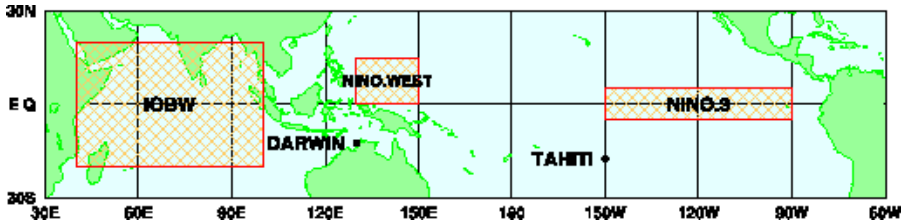
El Niño Southern Oscillation (ENSO)

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

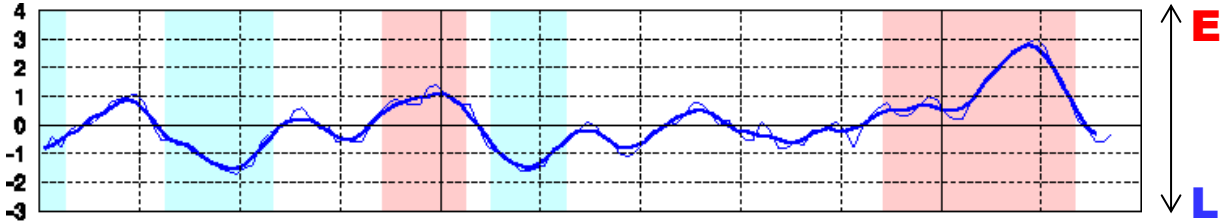
- SSTs in the central to eastern Pacific swing back and forth between a positive (El Niño) and negative (La Niña) phase on a cycle of 2-7 years.

- The influence of ENSO variability on the atmospheric circulation is felt globally through teleconnection.

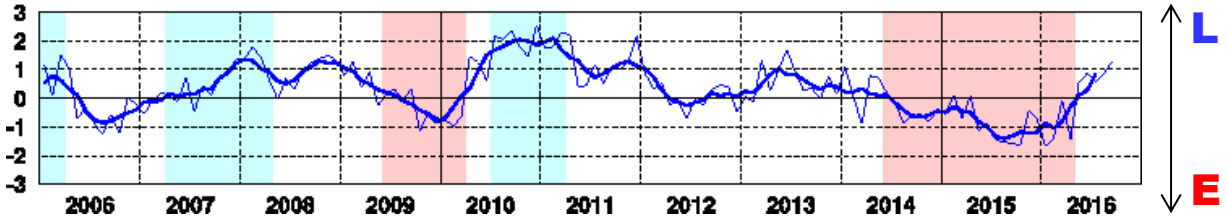




NINO.3 index



Southern Oscillation Index



The Southern Oscillation Index is defined as

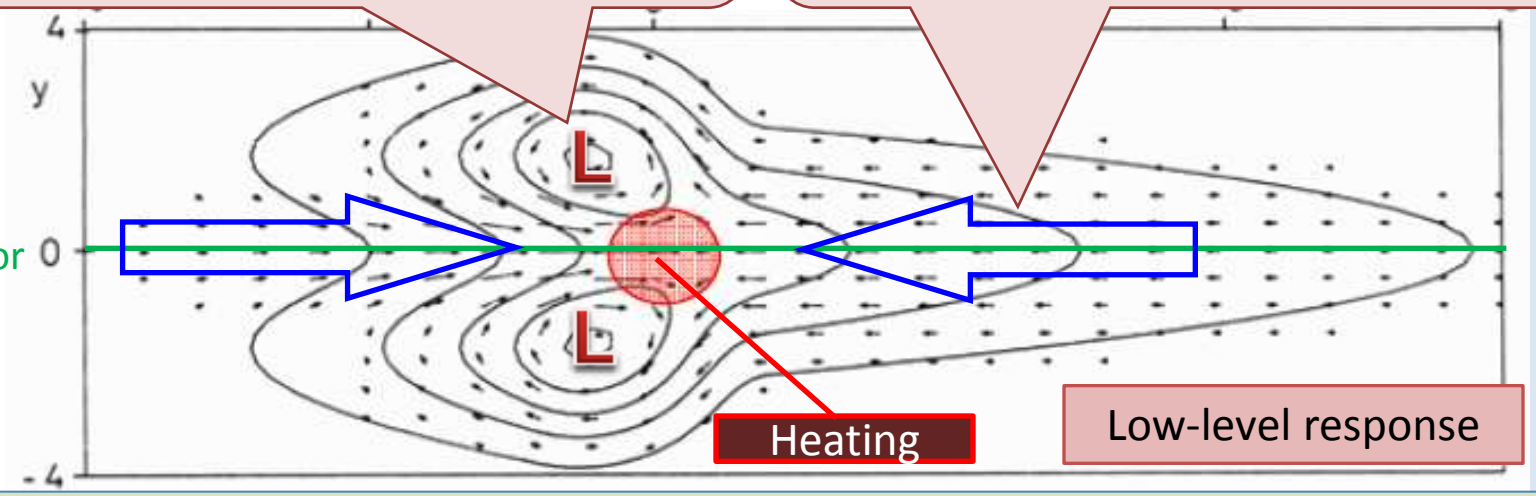
SOI = X / SD(X), where X = ANM(Ps(Tahiti))/SD(Ps(Tahiti)) - ANM(Ps(Darwin))/SD(Ps(Darwin))

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).



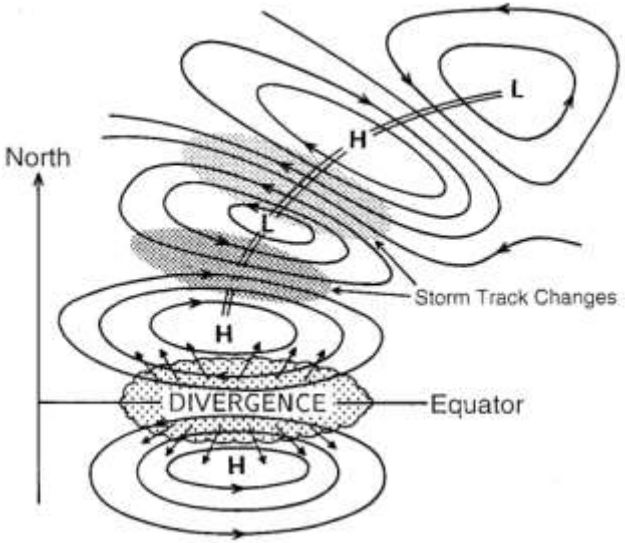
Atmospheric response in the lower troposphere to the heating symmetric about the equator

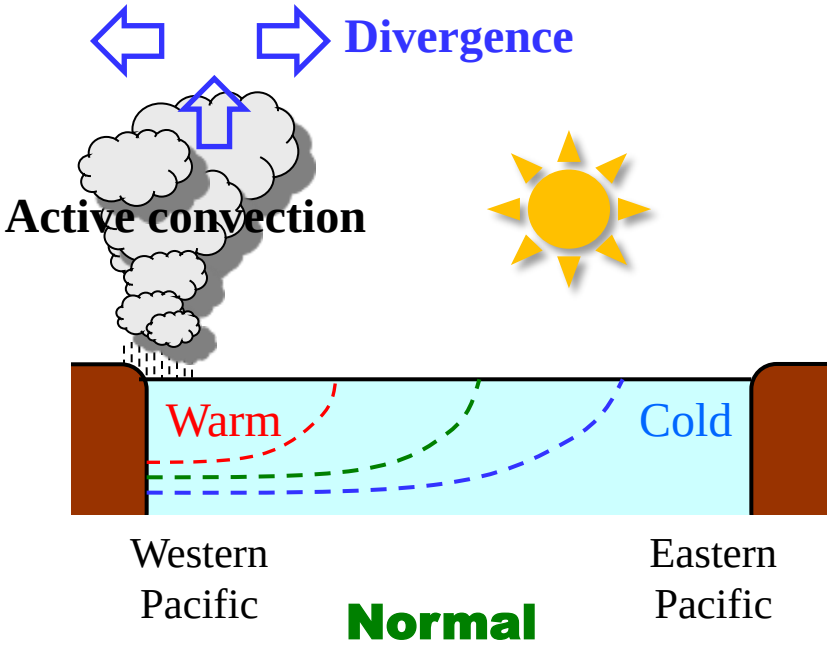
Contours indicate perturbation pressure, and vectors denote velocity field.
Red circle indicates the position of the heating. (Source: Gill 1980)

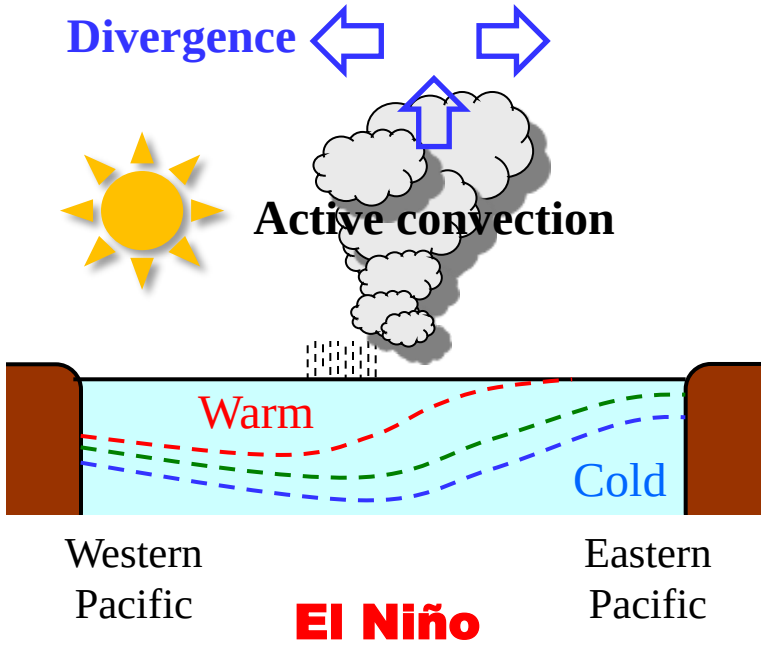
Upper-level response shows the reverse of the low-level response.

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).



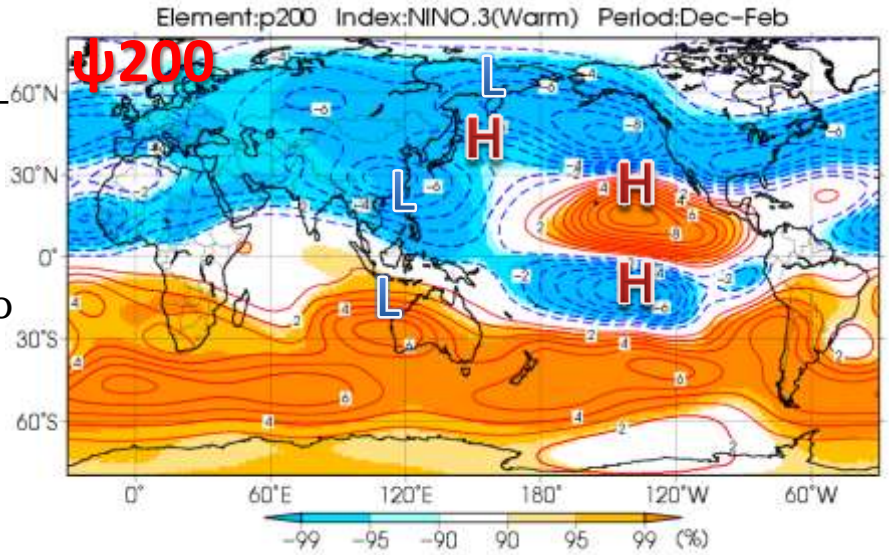


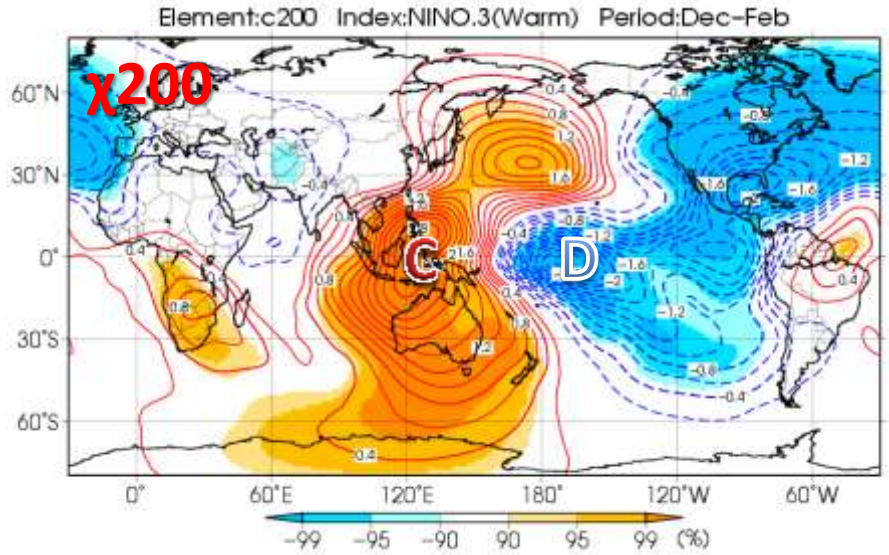


ENSO and atmospheric circulation (El Niño DJF)

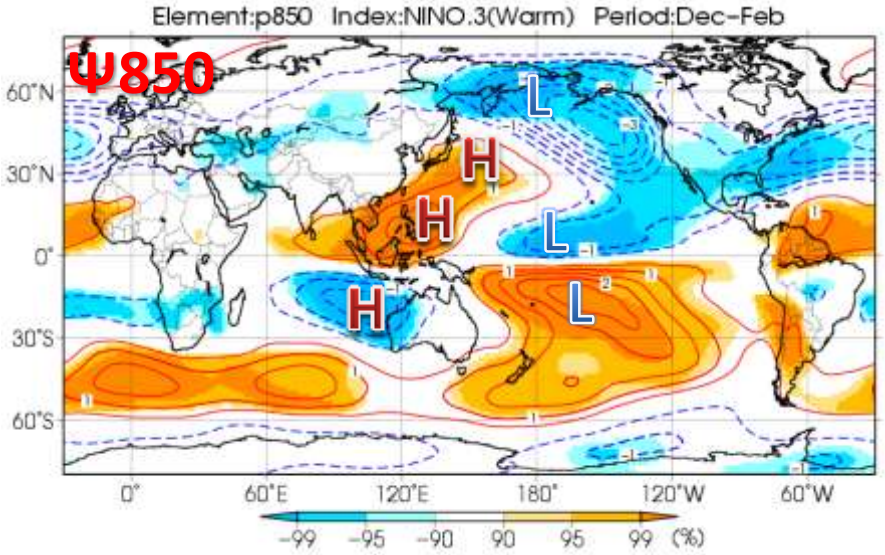
In December to February of El Niño years,

- 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.

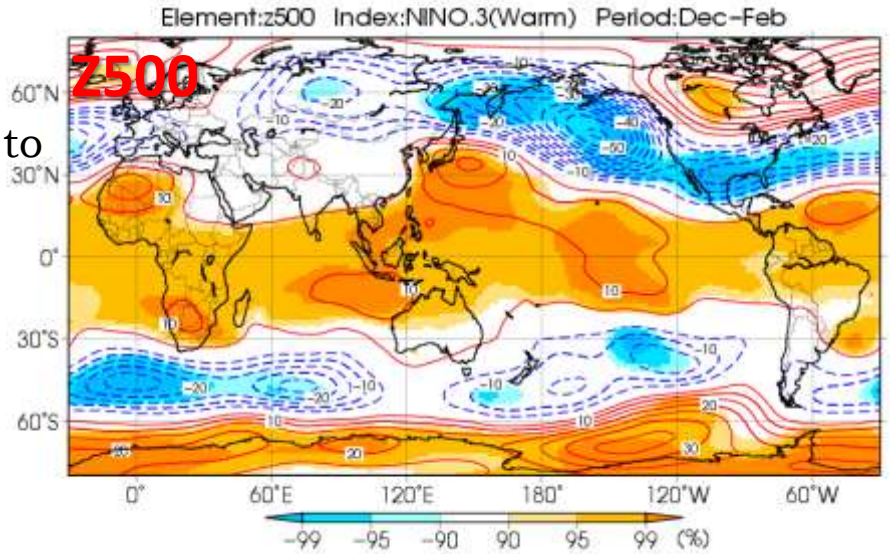


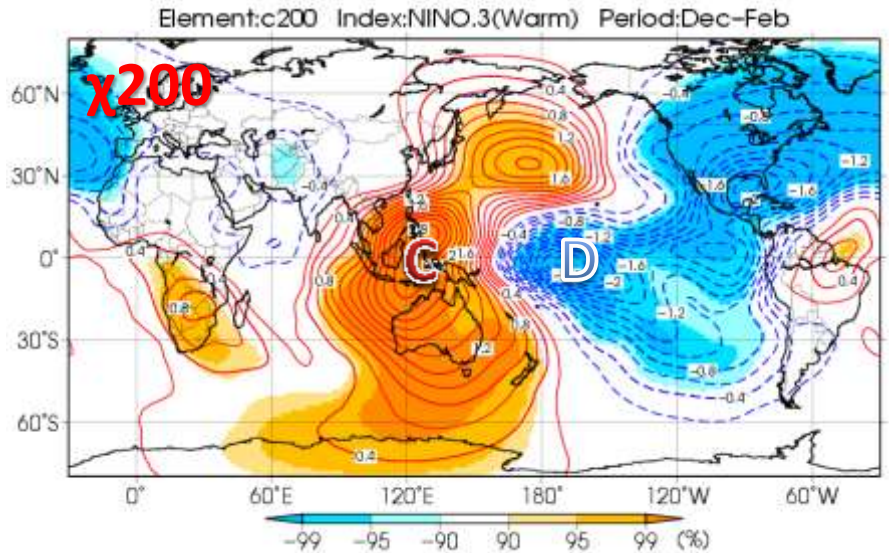
Composite **stream function anomalies** at 200hPa (top panel) and 850hPa (bottom panel) for DJF during past El Niño events

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.





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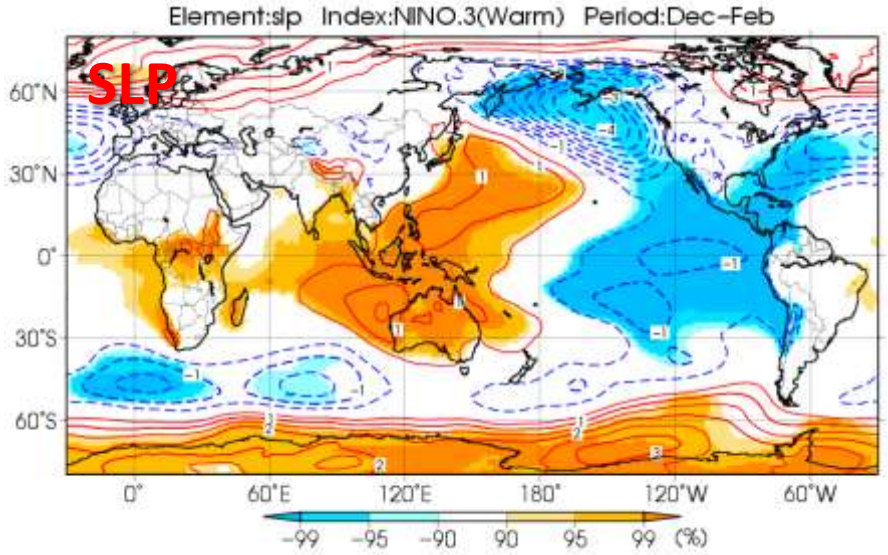
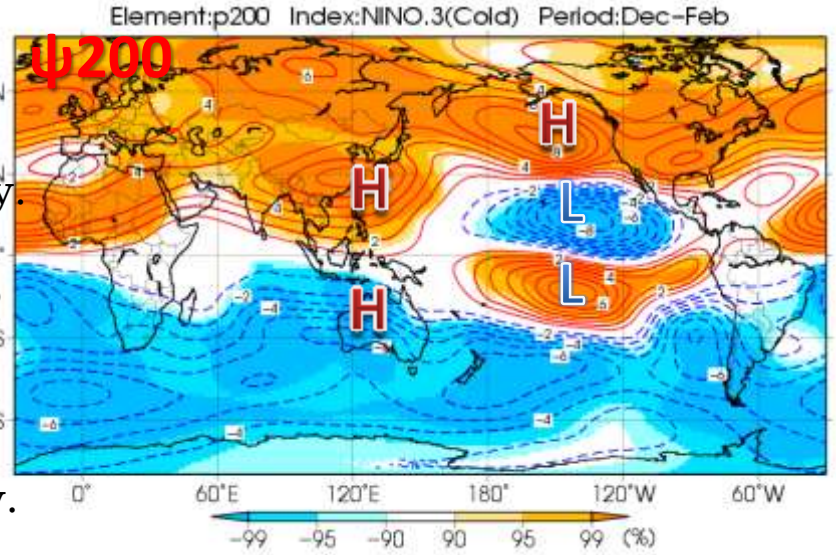


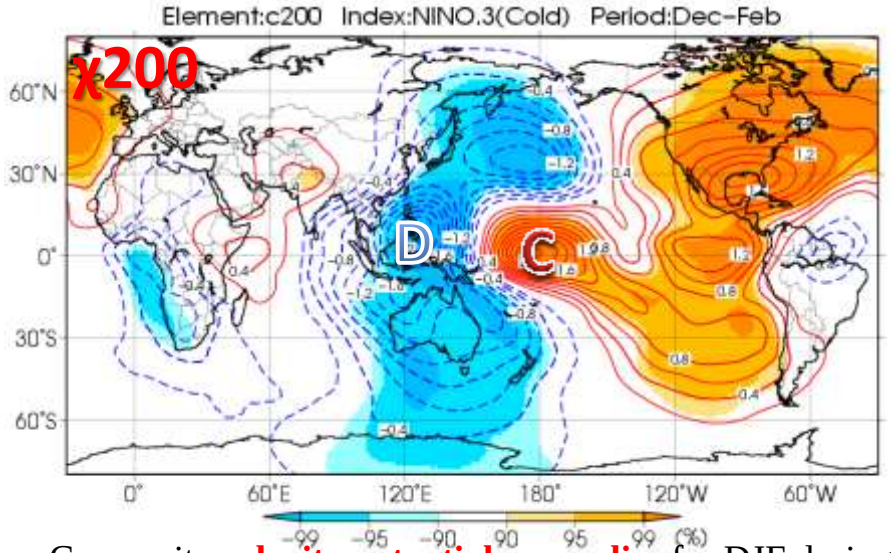
Composite anomalies of **500hPa height** (top) and **SLP** (bottom) for DJF during past El Niño events

ENSO and atmospheric circulation (La Niña DJF)

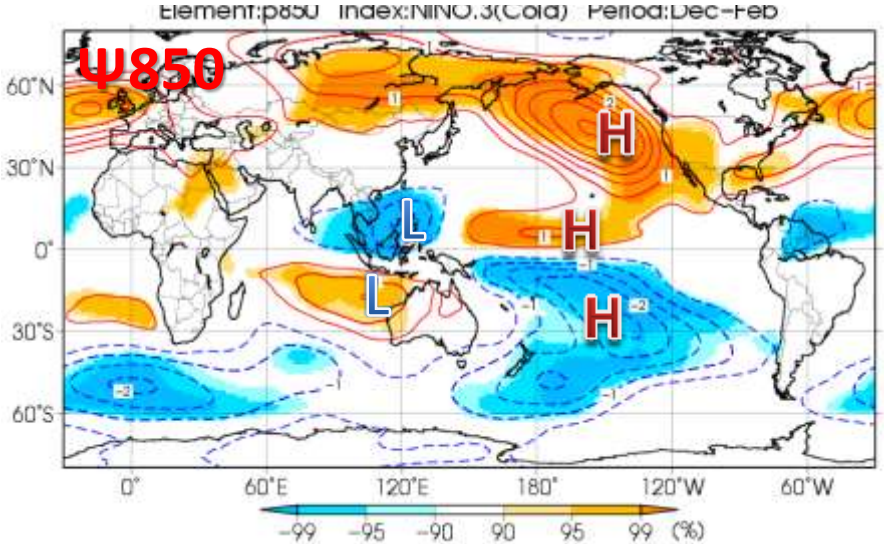
In December to February of La Niña years,

- 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.

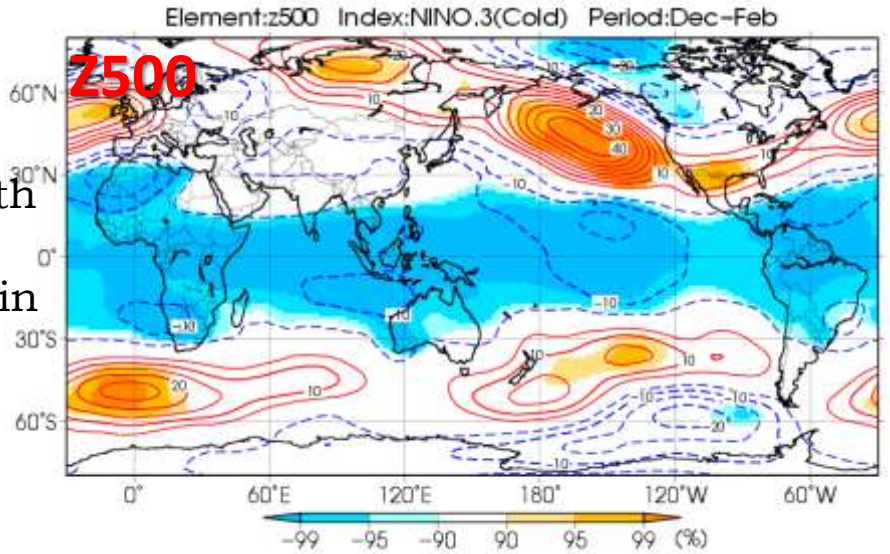


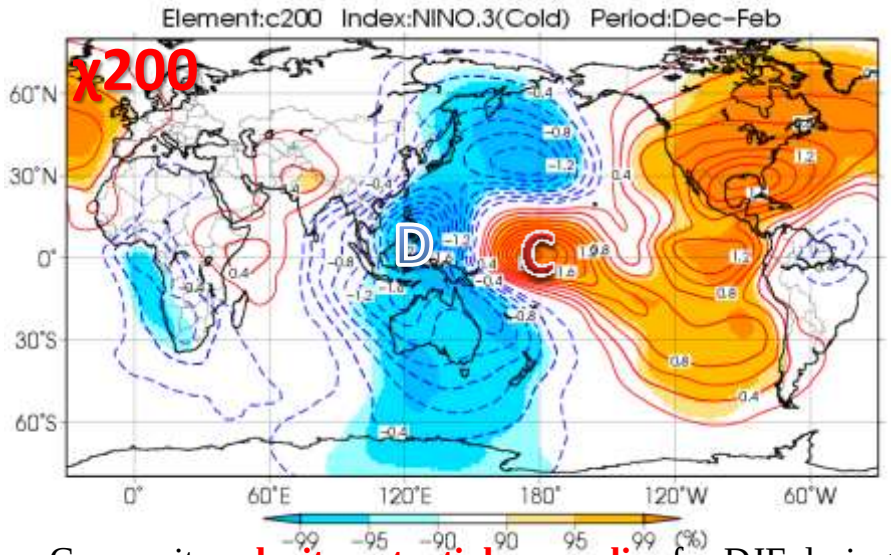
Composite **stream function anomalies** at 200hPa (top panel) and 850hPa (bottom panel) for DJF during past La Niña events

ENSO and atmospheric circulation (La Niña DJF)

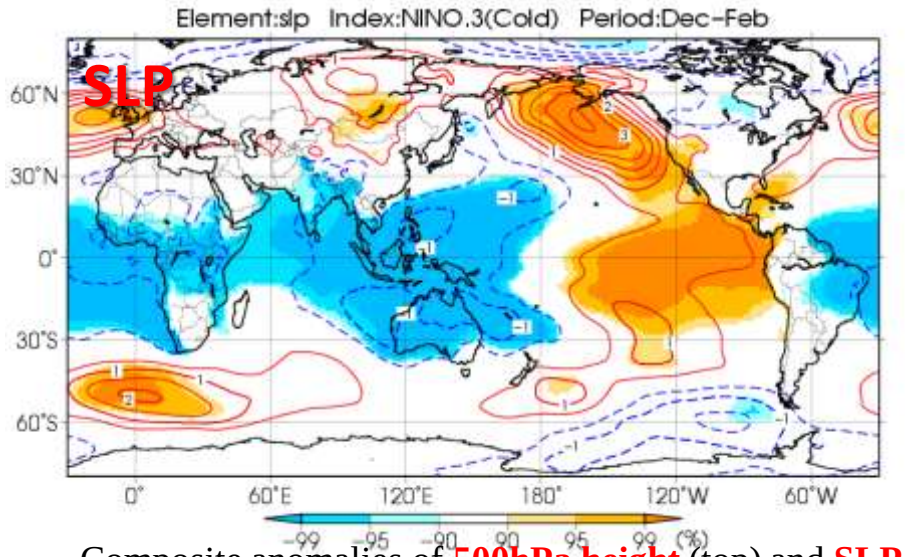
In December to February of La Niña years,

- 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.

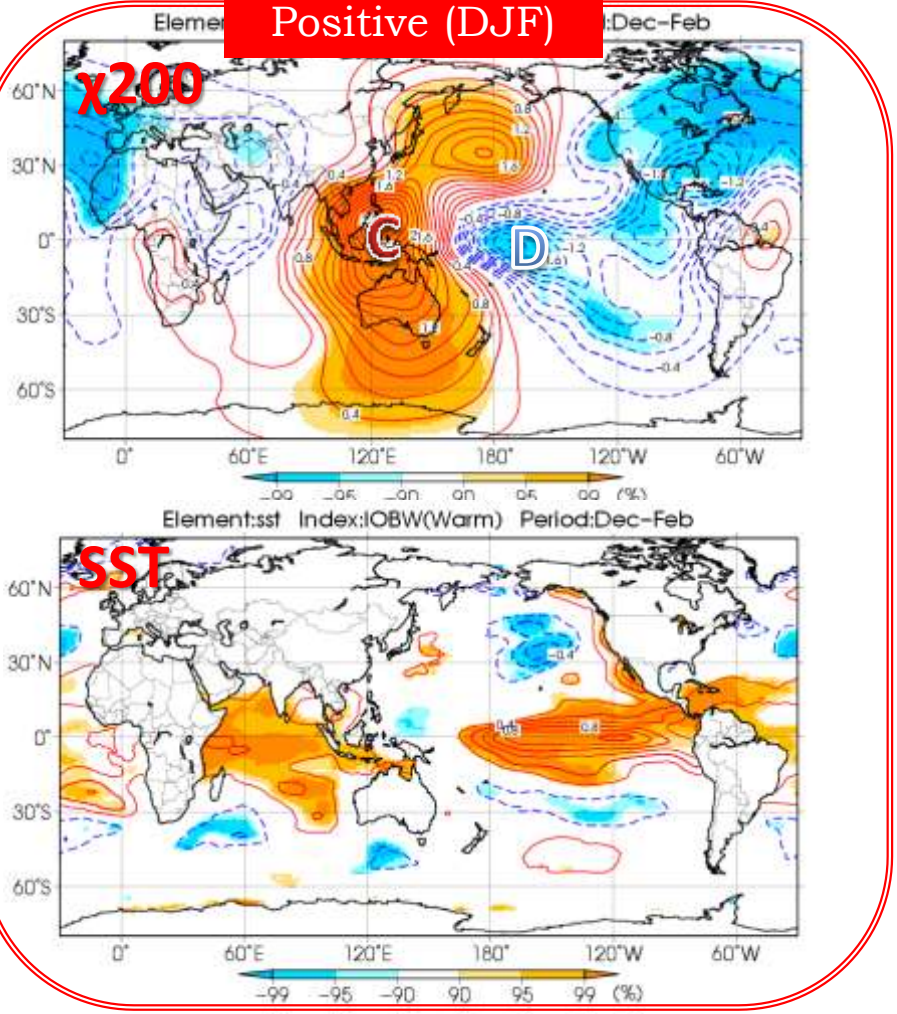


Composite anomalies of **500hPa height** (top) and **SLP** (bottom) for DJF during past La Niña events

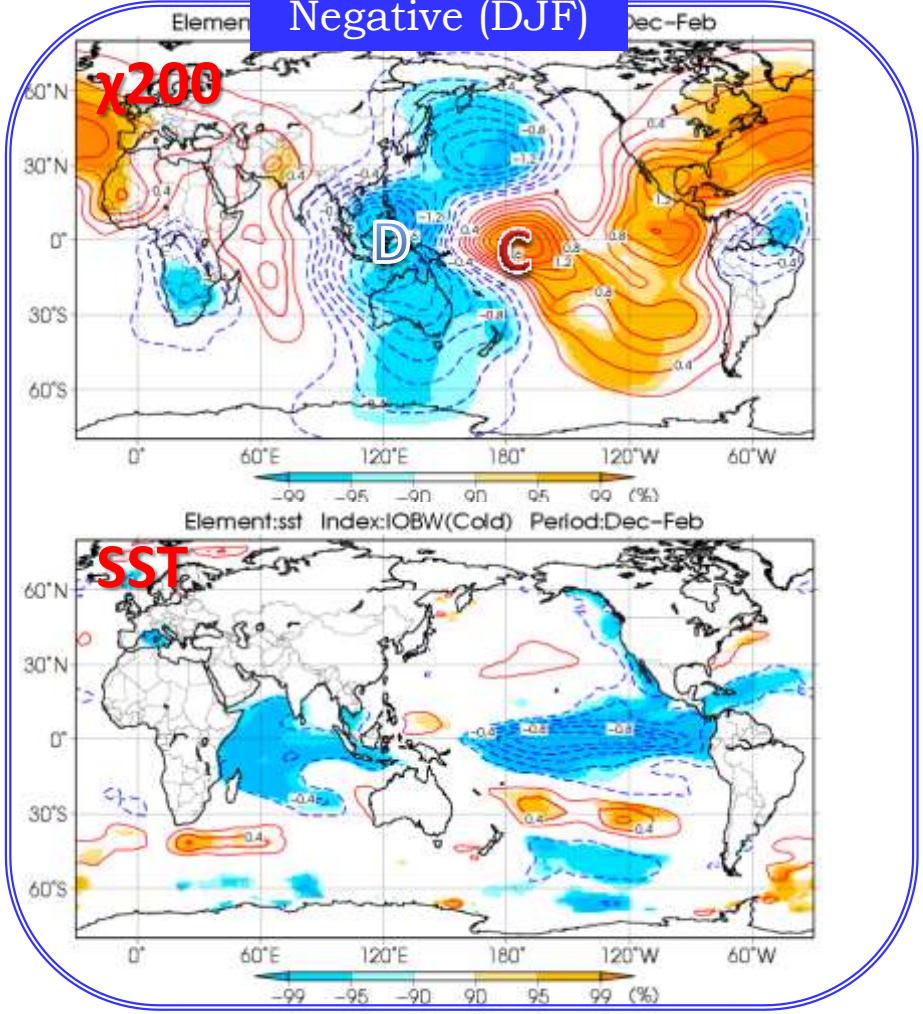
Indian Ocean Basin Wide

- As in the Pacific, SSTs in the Indian Ocean are known to fluctuate between a positive and negative phase basin-wide.
- IOBW tends to follow in the wake of ENSO with a delay of around 3 months.

Positive (DJF)



Negative (DJF)

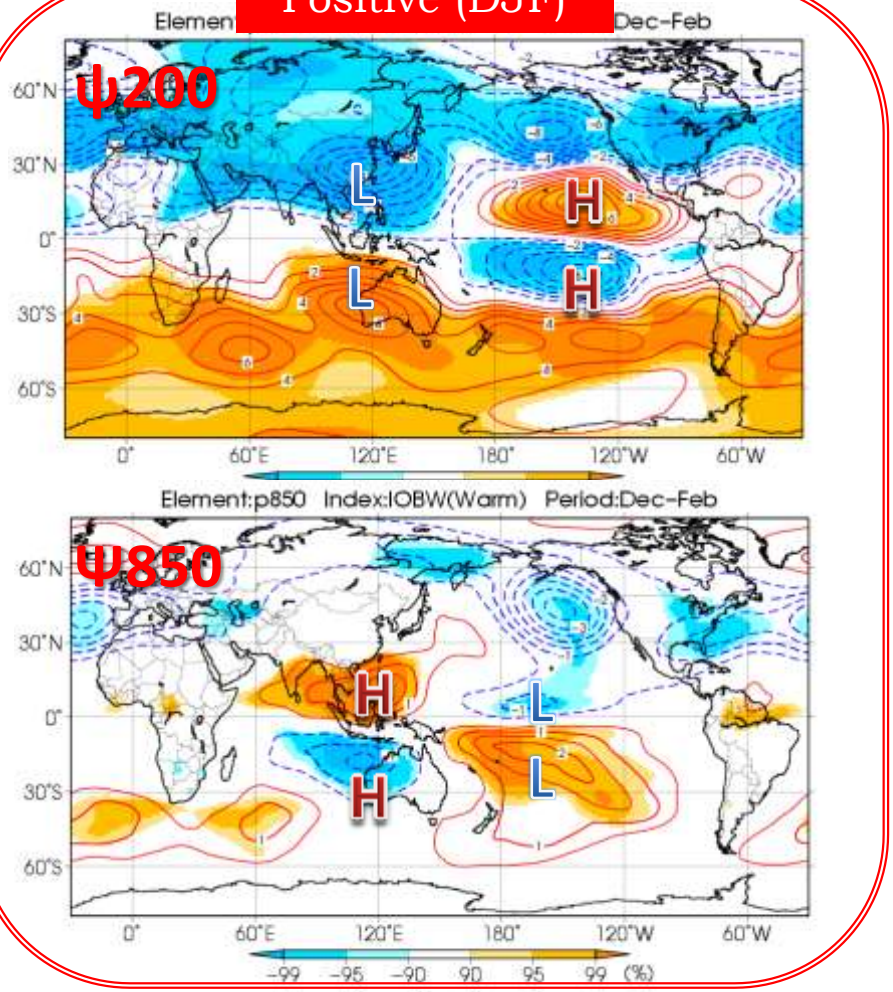


Indian Ocean Basin Wide

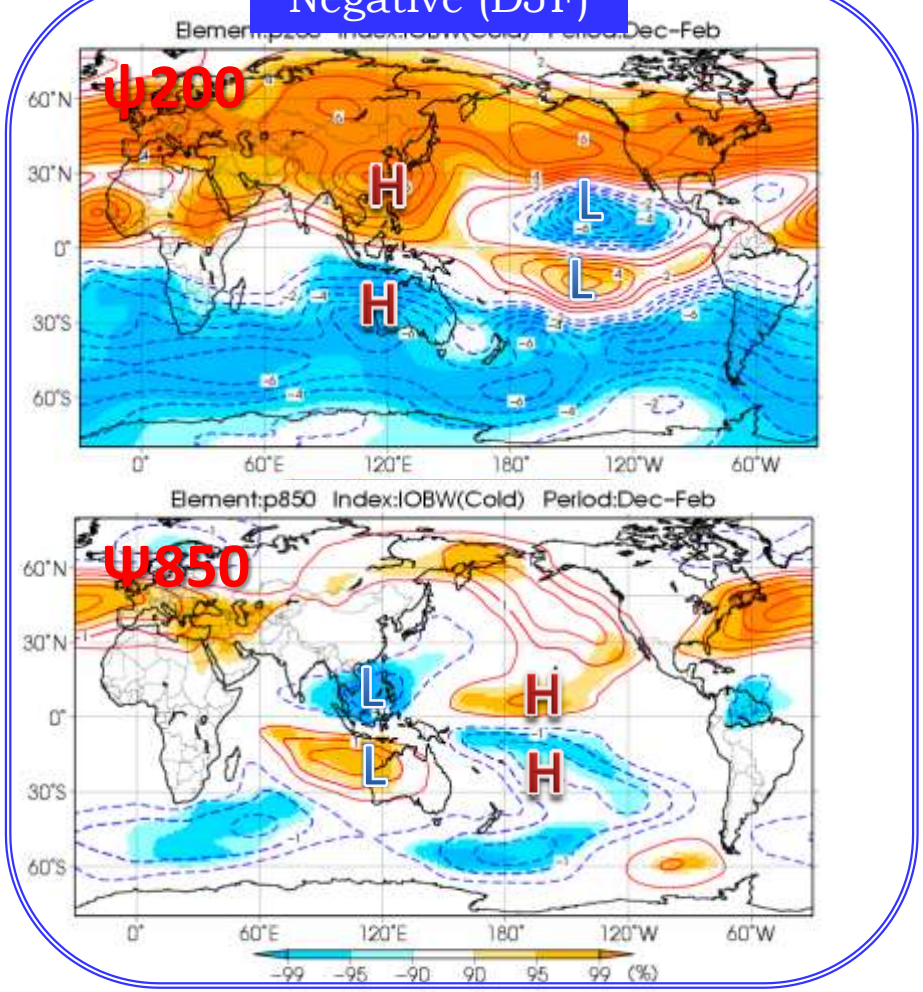
In December to February of positive IOBW years,

- 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)



Negative (DJF)



ENSO/IOBW-related supplementary materials

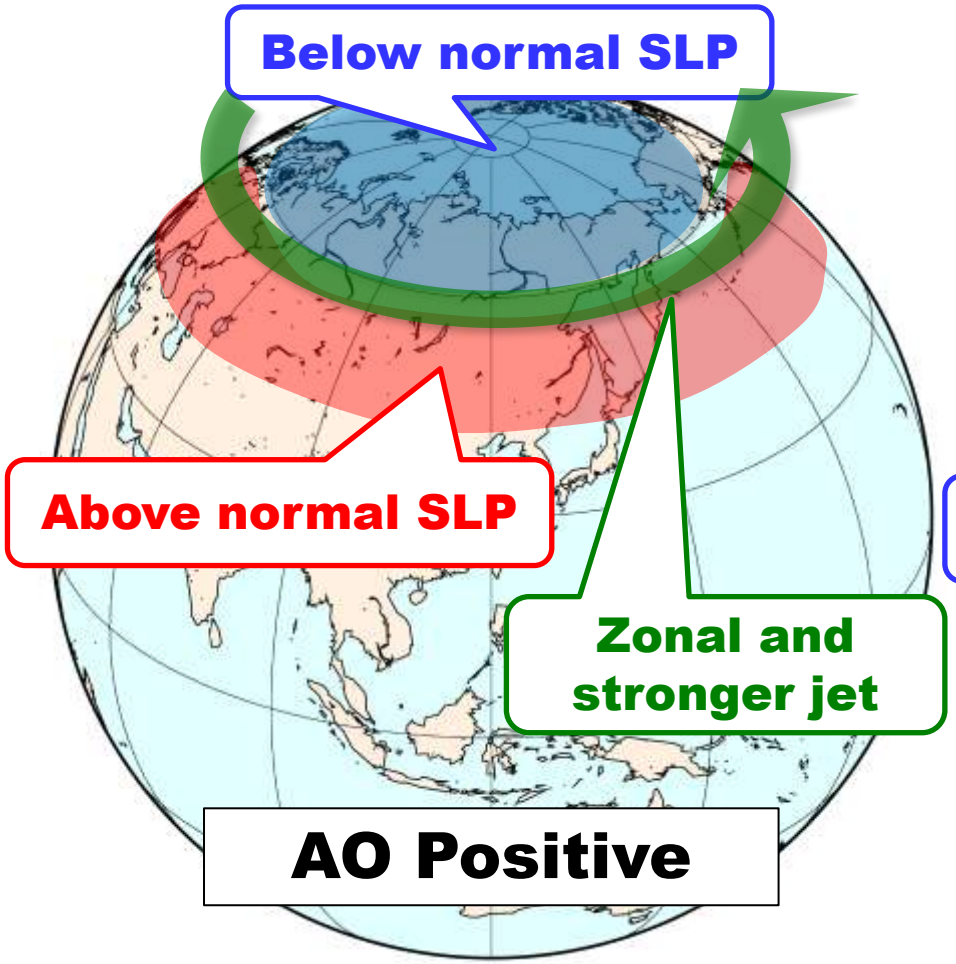
- For participants' reference, more detailed composite maps of global circulation anomalies associated with ENSO and IOBW are available at the TCC web site. Please visit
  http://ds.data.jma.go.jp/tcc/tcc/products/clisys/enso_statistics/index.html

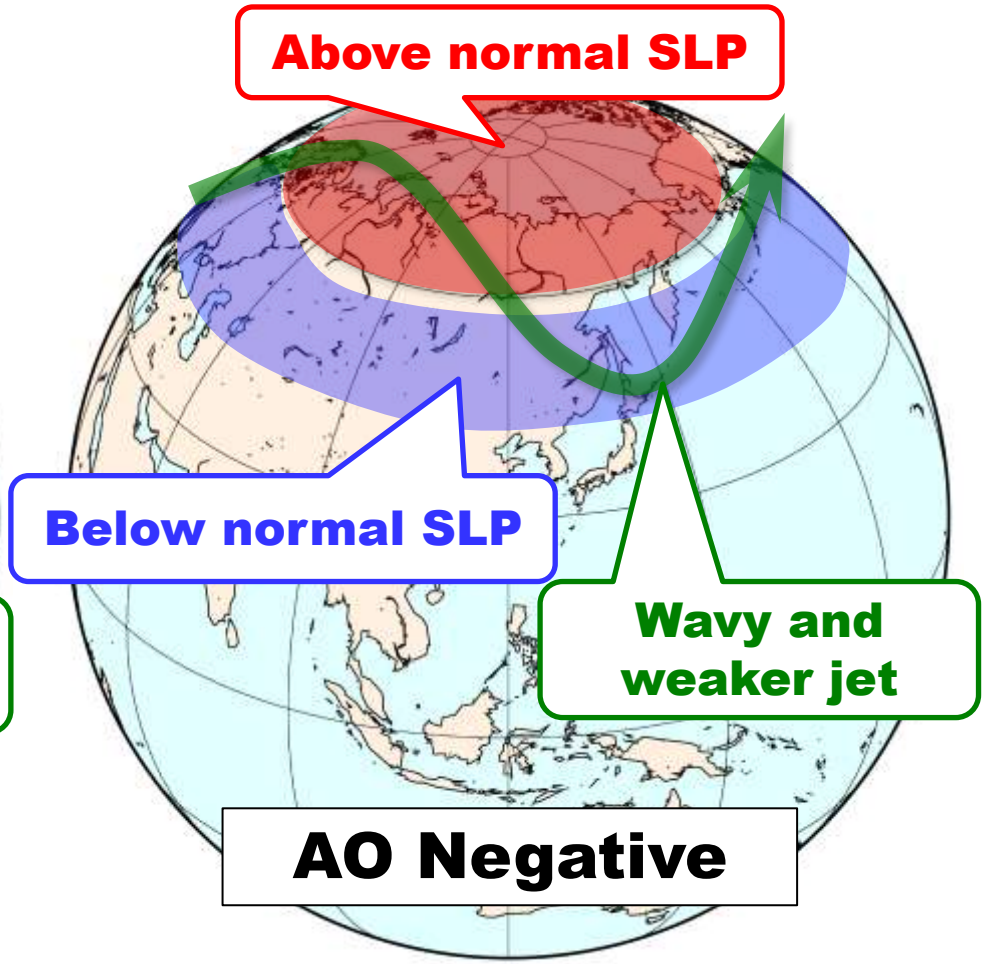
  or alternatively, it might be much easier to google:

TCC composite map search

Arctic Oscillation (AO)

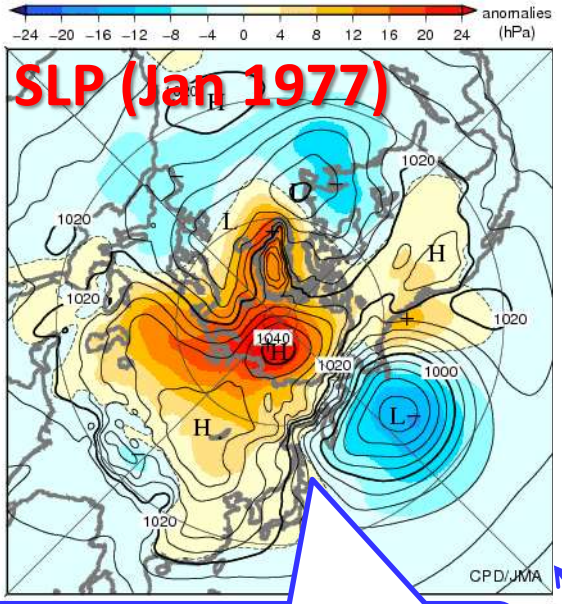
- A seesaw-like oscillation of pressure anomalies between the Arctic and mid-latitudes which dominates climate variability in boreal winter.
- In a positive phase of AO, cold air mass tends to be confined in the Polar region, leading to a warm winter in mid-latitudes.
- In a negative phase of AO, cold air mass flows southward from the Polar region, leading to a cold winter in mid-latitudes.

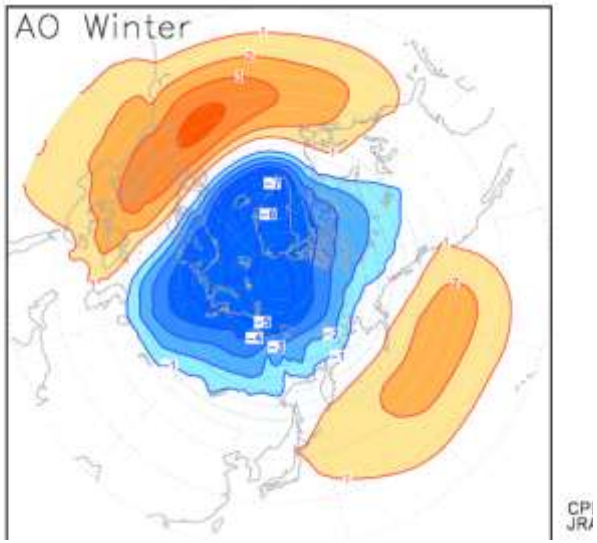


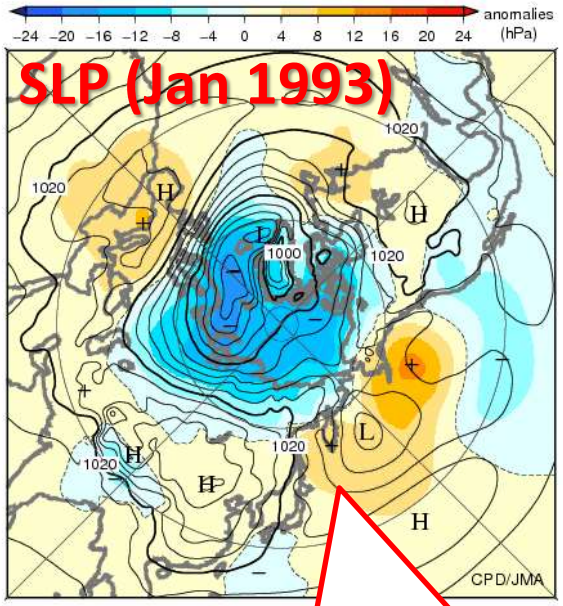


Definition and AO index

- In the operational analysis at JMA, the AO pattern is defined as the leading mode of Empirical Orthogonal Function (EOF) analysis of monthly mean SLP during 1958-2012 winters (see the central figure below).
- The AO index indicates the degree of similarity between observed SLP anomalies and the defined AO pattern.





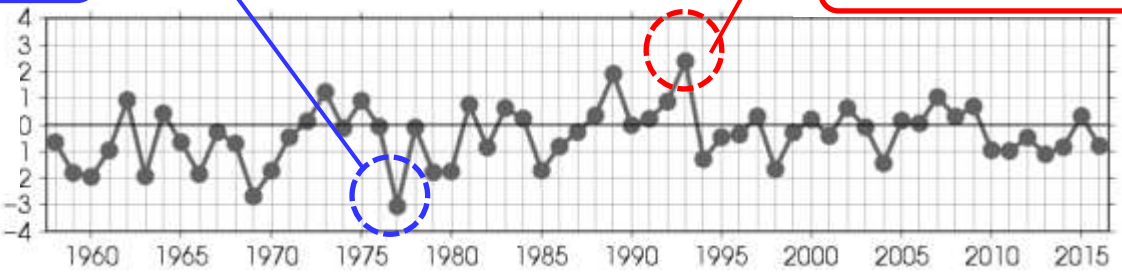


Strongly negative

SLP anomalies for positive AO (definition)

Strongly positive

Monthly AO index for January

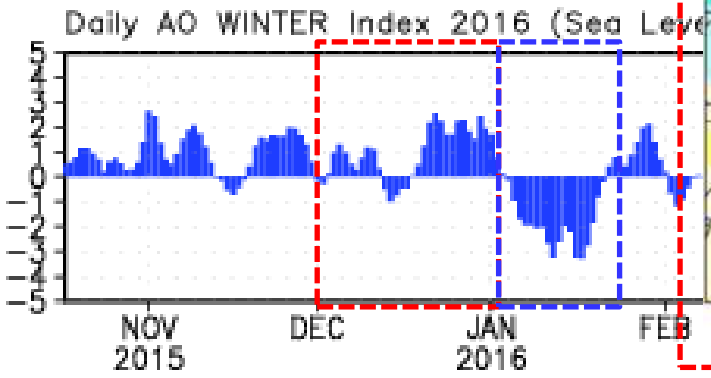


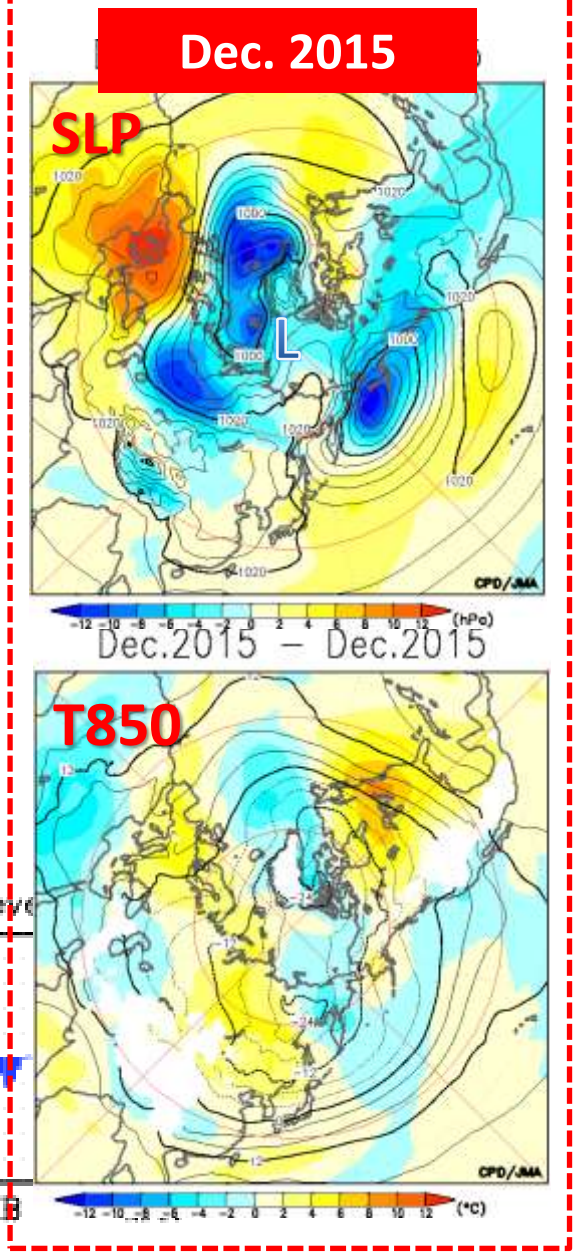
AO and atmospheric circulation

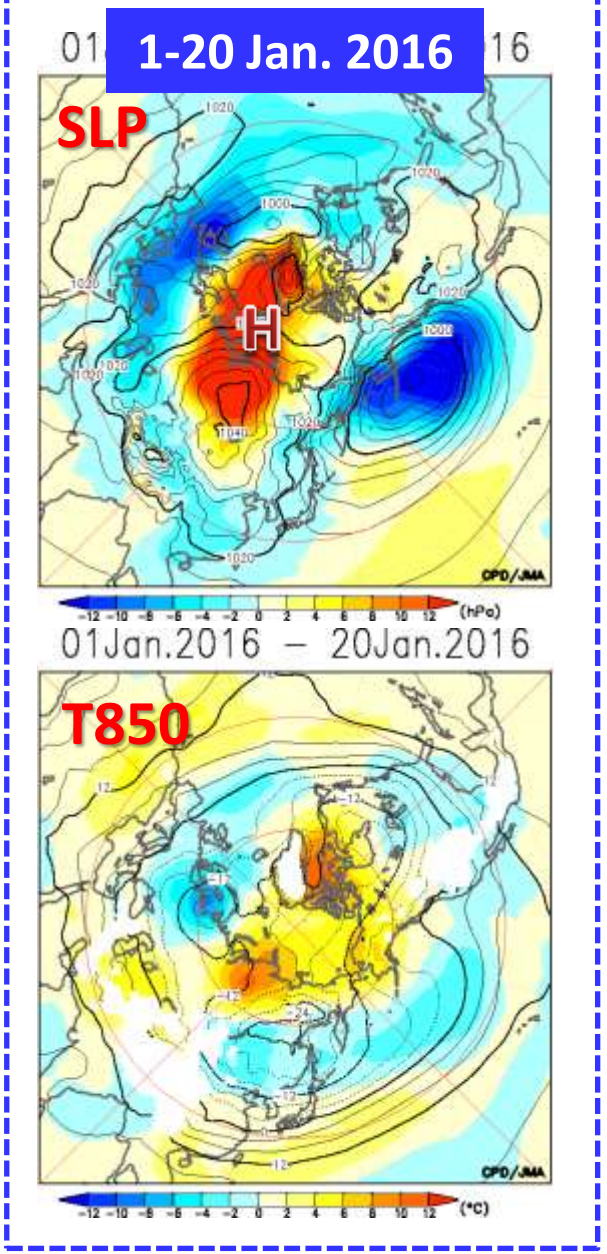
- Around the end of Dec 2015, the phase of AO suddenly turned from positive to negative.

- In association, Northeast Asia experienced warm December and cold January.

Daily AO index







Eurasia pattern (EU)

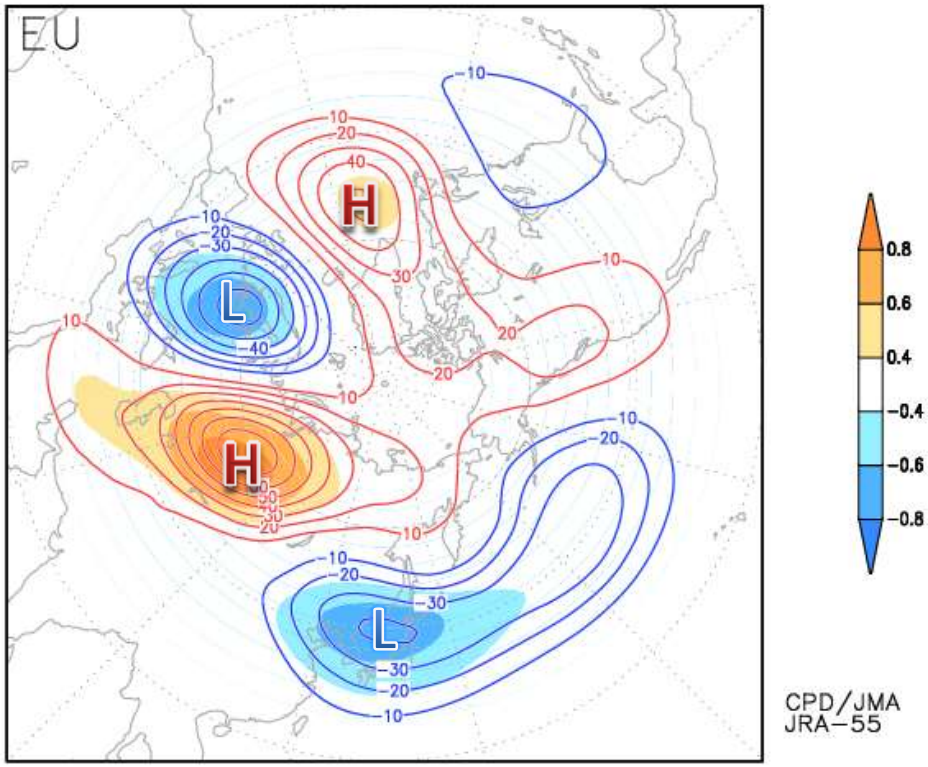
- In the operational analysis at JMA, the EU pattern is defined as anomalies in monthly mean 500hPa height field regressed on the EU index during 1958-2012 winters.

- The EU index is composed from monthly mean 500hPa height anomalies at three grid points:

$$EU = -\tfrac{1}{4}z^*(55°N, 20°E) + \tfrac{1}{2}z^*(55°N, 75°E) - \tfrac{1}{4}z^*(40°N, 145°E),$$

- The EU pattern is interpreted as a Rossby wave train extending from the North Atlantic through Siberia down to East Asia along the polar jet stream.

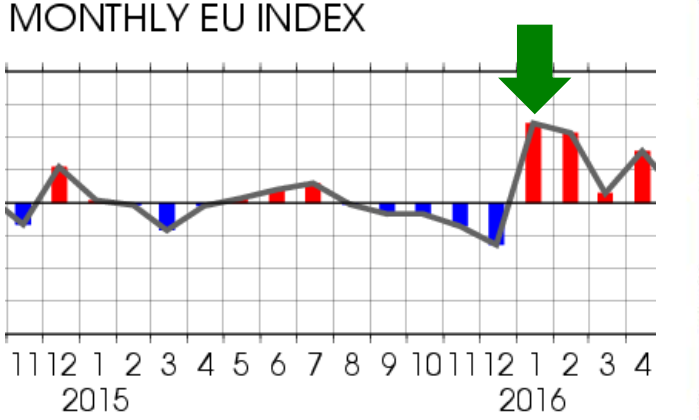
500hPa height anomalies representing the positive EU pattern

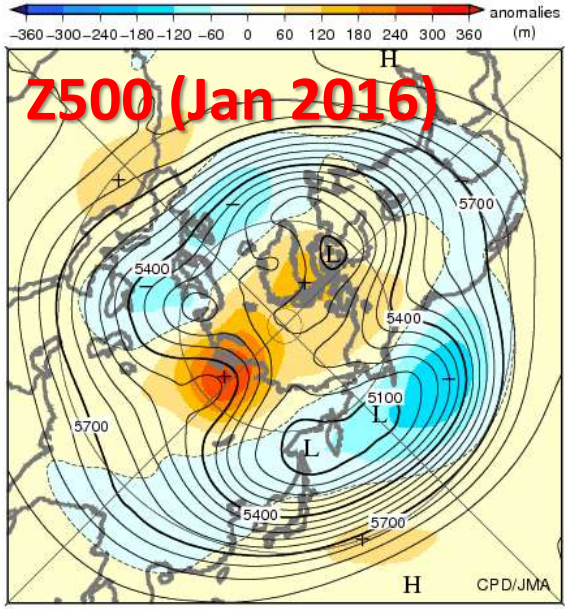


EU pattern and atmospheric circulation

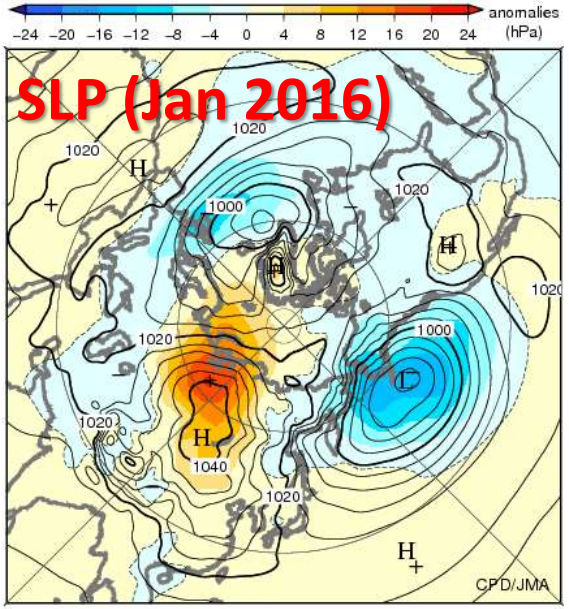
- The positive EU pattern is associated with an enhanced 500hPa ridge over Siberia (the central figure below) and intensification of the Siberian High (the right figure below).

- Hence the positive EU is often connected to a cold air mass outbreak and leads to an unusually freezing episode over East Asia and sometimes Southeast Asia as well.





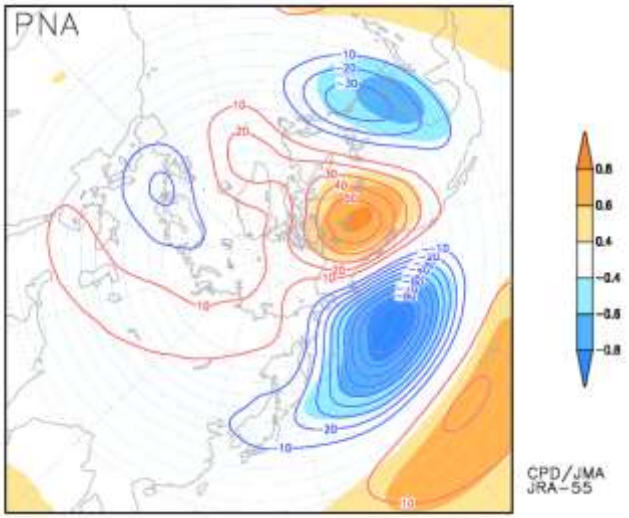
Monthly mean 500 hPa height and anomaly in the Northern Hemisphere (Jan.2016)
The contours show height at intervals of 60 m.
The shading indicates height anomalies.
Anomalies are deviations from the 1981–2010 average.



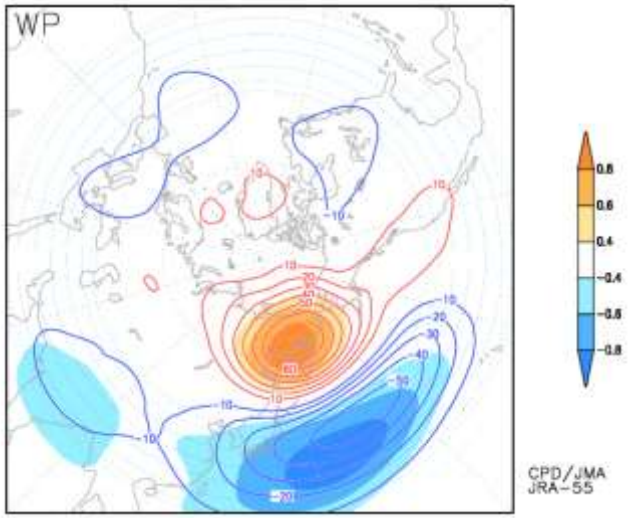
Monthly mean sea level pressure and anomaly in the Northern Hemisphere (Jan.2016)
The contours show sea level pressure at intervals of 4 hPa.
The shading indicates sea level pressure anomalies.
Anomalies are deviations from the 1981–2010 average.

Other known modes of variability

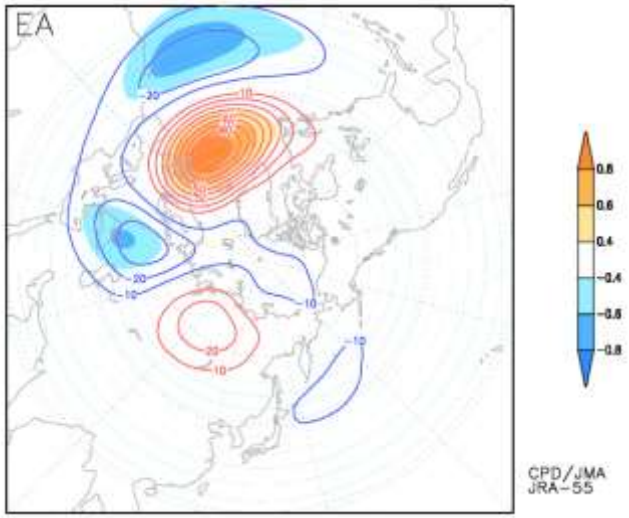
Pacific-**N**orth **A**merica pattern



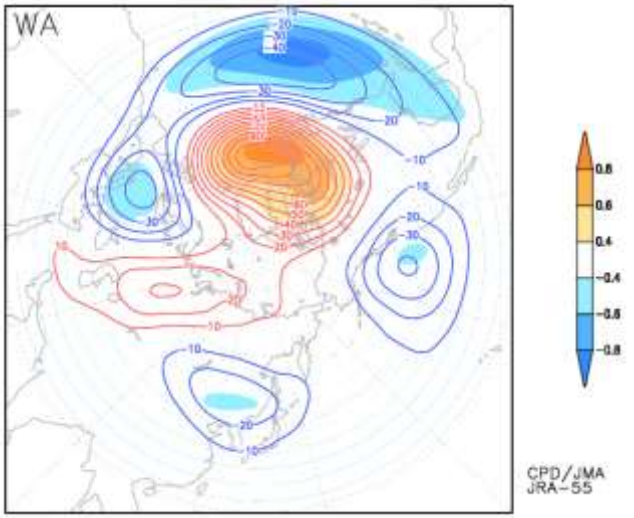
Western **P**acific pattern



Eastern **A**tlantic pattern



Western **A**tlantic pattern



Some remarks before concluding

- In the exercise session of this seminar, participants are requested to research on a relationship between a primary mode of variability of their choice and climate conditions in their own country.

- So please remind that you are going to discover the mode of variability which is of the greatest concern to your country's climate.

Thank you for your attention.