Intra-seasonal variations in the tropical atmospheric circulation

Climate Prediction Division
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TCC training seminar on 1st December 2009

Outline

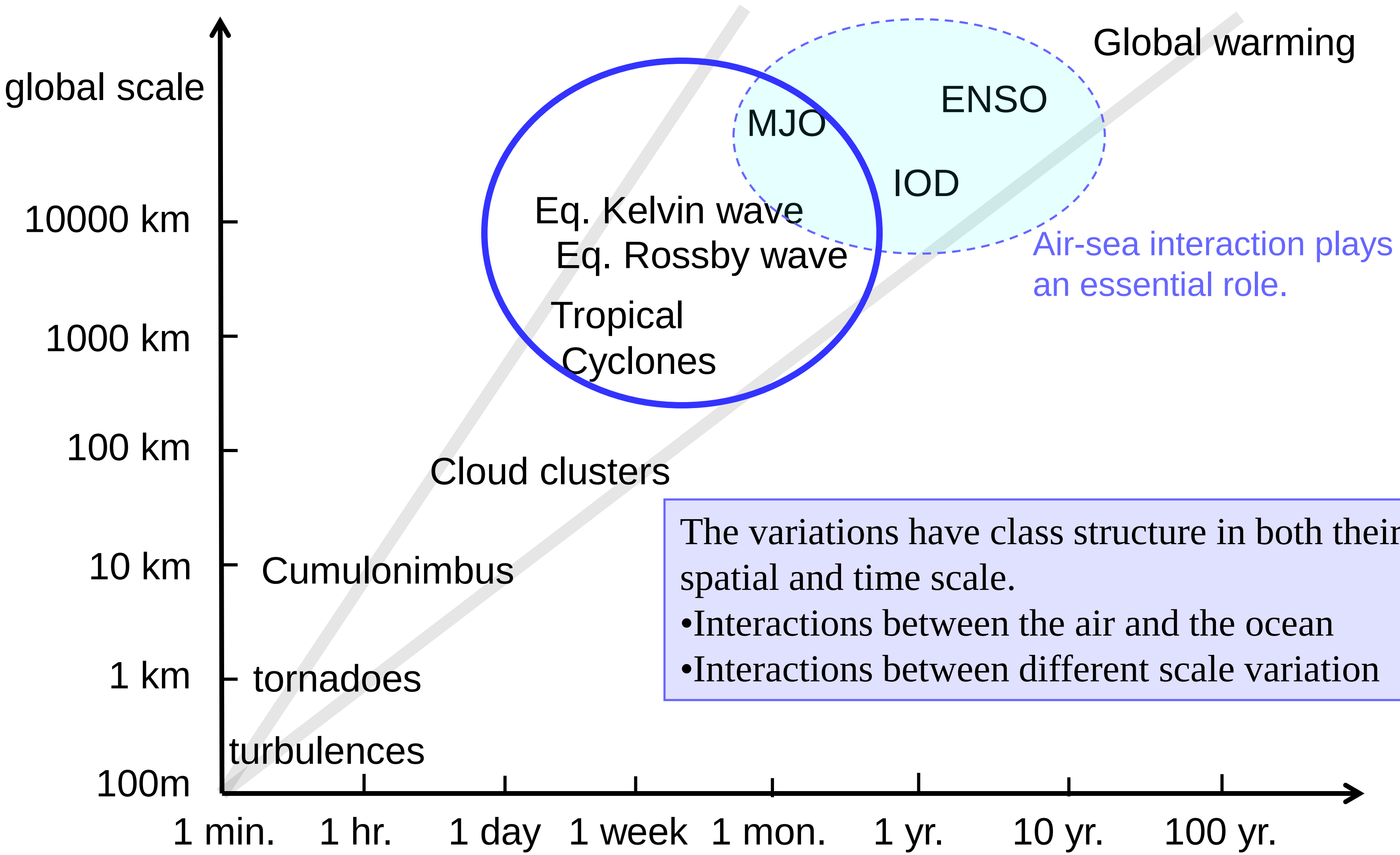
- The importance of the tropical circulations
- Atmospheric variations in the tropics
  - Madden-Julian Oscillation（MJO）
  - Equatorial Kelvin waves
  - Equatorial Rossby waves
  - Intra-seasonal variations in the Asian summer monsoon
- Interaction between different scale variations

The importance of the tropical circulations

- From a perspective of the disaster prevention…
  - Extreme weather conditions (e.g. strong winds, heavy rainfall, high tides etc.) associated with tropical storms sometimes cause serious disasters.
  - The occurrence and development of tropical storm is closely related to the larger scale variations (equatorial waves, MJO, ENSO etc).
  - Convection/circulation anomalies in the tropics can influence all over the world through “teleconnections.”

In this lecture, we will overview the tropical variations with the intraseasonal timescale, as a first step.

The variations in the tropics



The variations have class structure in both their spatial and time scale.

- Interactions between the air and the ocean
- Interactions between different scale variation

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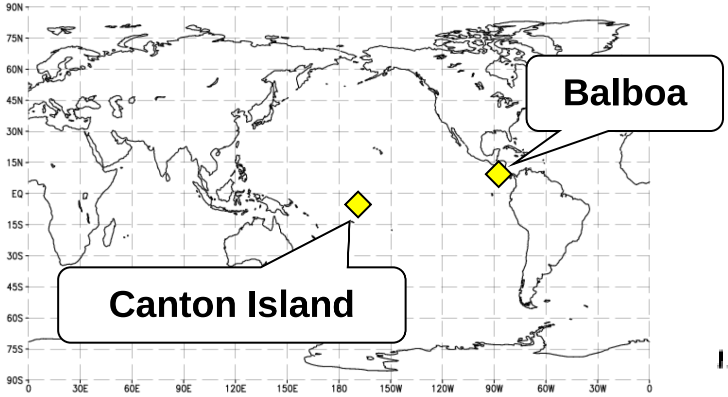
Madden-Julian Oscillation

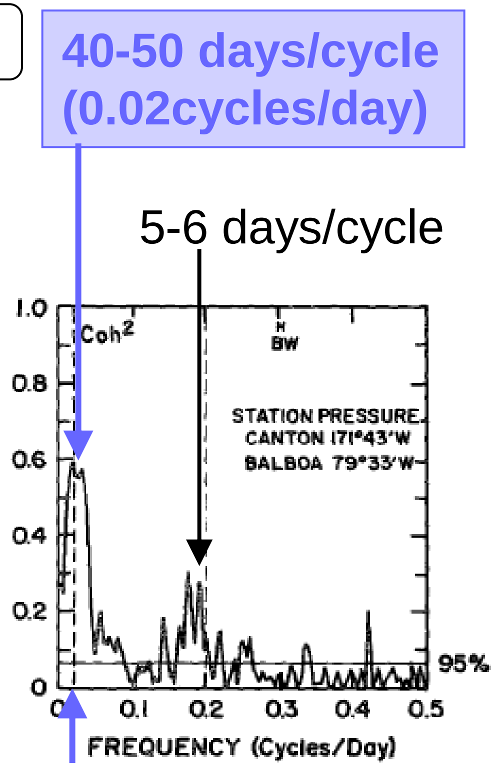
Dr. Roland A. Madden



In 1960s or 1970s, tropical data were so sparse.
Madden and Julian (1971) analyzed the nearly 10-year observation data (surface pressure) at Canton Island and Balboa (Madden and Julian 1971).

They discovered two periods band:
One is at 5-6 days period, and
the other is at 12- to 100-day periods with the maximum at 40-50 days.

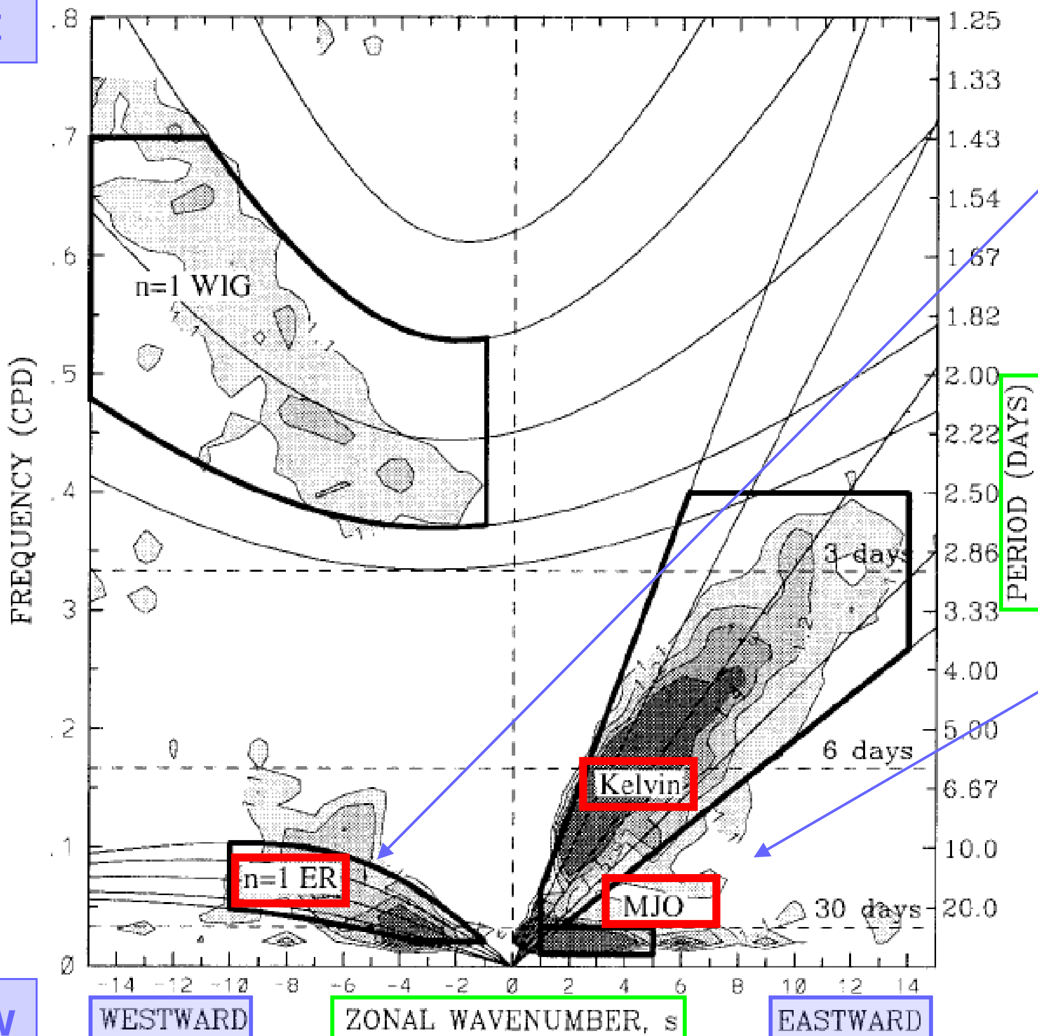
The Madden-Julian Oscillation



Power spectrum of the surface pressure at Canton Island (2.8ºN,171.7ºW)

Madden-Julian Oscillation

Fast



Slow

Equatorial Rossby wave propagates westwards and has about 30 days period.

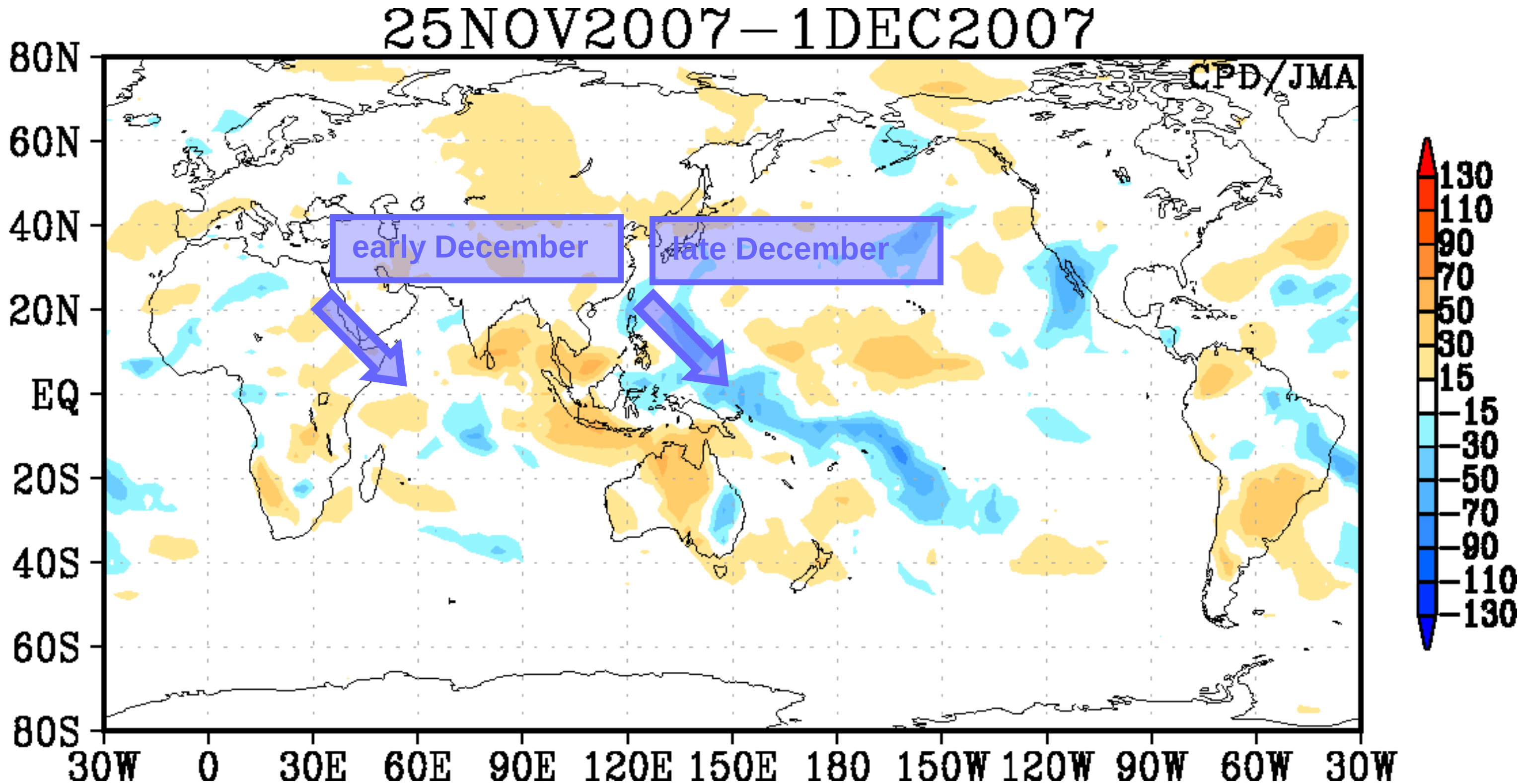
Both Kelvin wave and MJO propagate eastwards.

Their period bands are different.

Power spectrum of wavenumber-frequency using filtering of the OLR dataset. The thin lines indicate the various equatorial wave dispersion curves in the theory (Wheeler et al. 2000).

Dr. Wheeler

Madden-Julian Oscillation



7-day mean OLR anomalies (W/m^2).

Blue shadings ----> enhanced convections

Red shadings ----> suppressed convections

150˚-60˚E/20 days =4.5˚/day !

In the tropics, we sometimes observe large scaled convection anomalies propagating eastward. Enhancement of the convective activities is clear over the Indian Ocean. How much is the speed of the MJO propagation (degree longitude per day) ?

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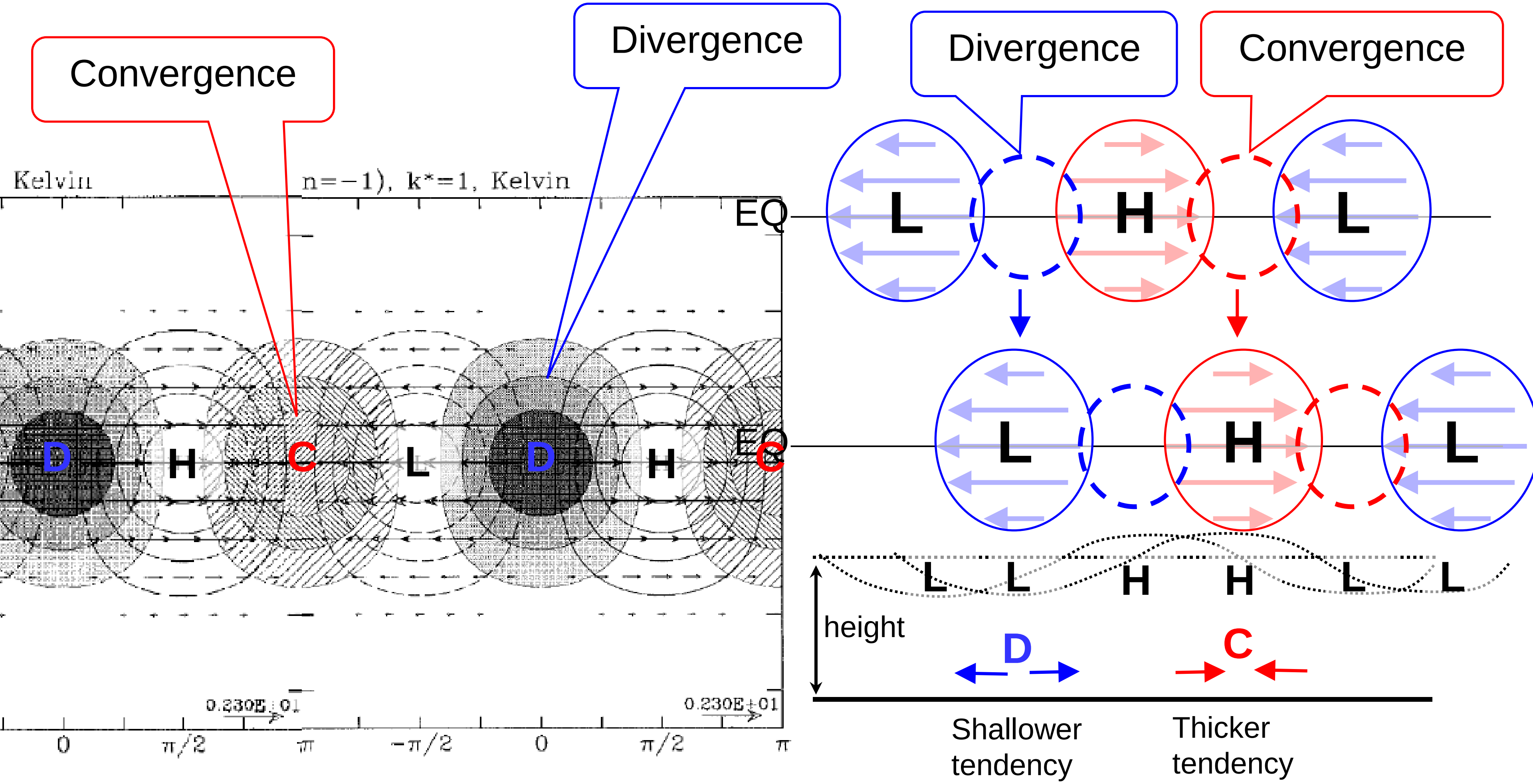
Equatorial Kelvin waves

- Equatorial waves
  - Equatorial waves are an important class of eastward and westward propagating disturbances in the atmosphere that are trapped near the equator.
  - Diabatic heating by organized tropical convection can excite atmospheric waves.

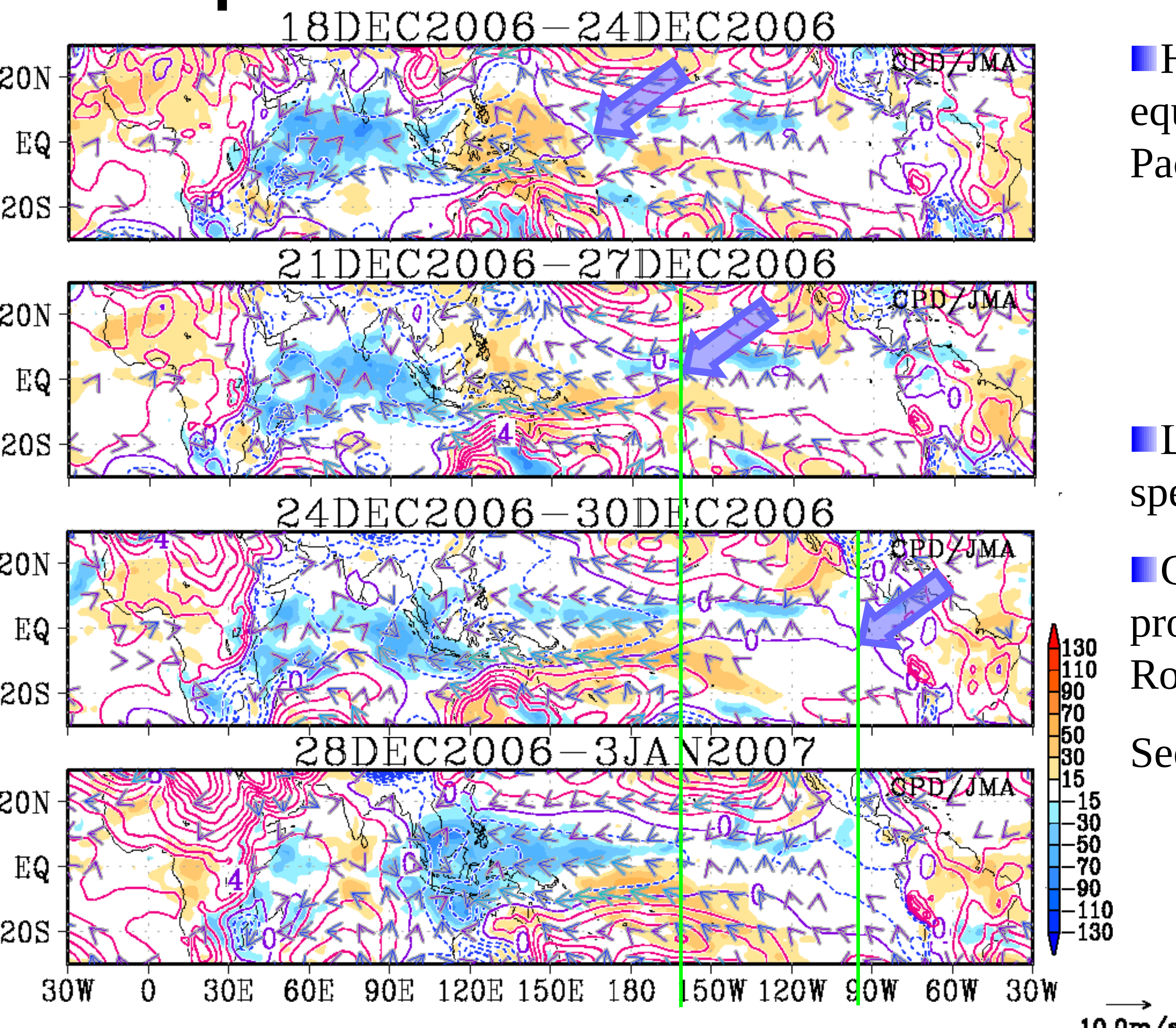
- Equatorial Kelvin waves
  - Equatorial Kelvin waves are basically gravity waves trapped near the equator because of the latitudinal variations of the Coriolis parameter.

Equatorial Kelvin waves



The theoretical equatorially trapped Kelvin wave solution to the linear shallow water equations on an equatorial beta plane (Wheeler et al. 2000, Matusno 1966)

Equatorial Kelvin waves



- How much speed does the equatorial Kelvin wave over the Pacific Ocean?

162˚-95˚W/3 days =22˚/day !

- Let's compare with the phase speed of the MJO.
- Can the equatorial Kelvin wave propagate over the Andes and the Rocky Mountains ?

See also Weickmann 1997

7-day mean SLP anomaly (contours), OLR (shading) and 10-m wind anomaly (vectors)

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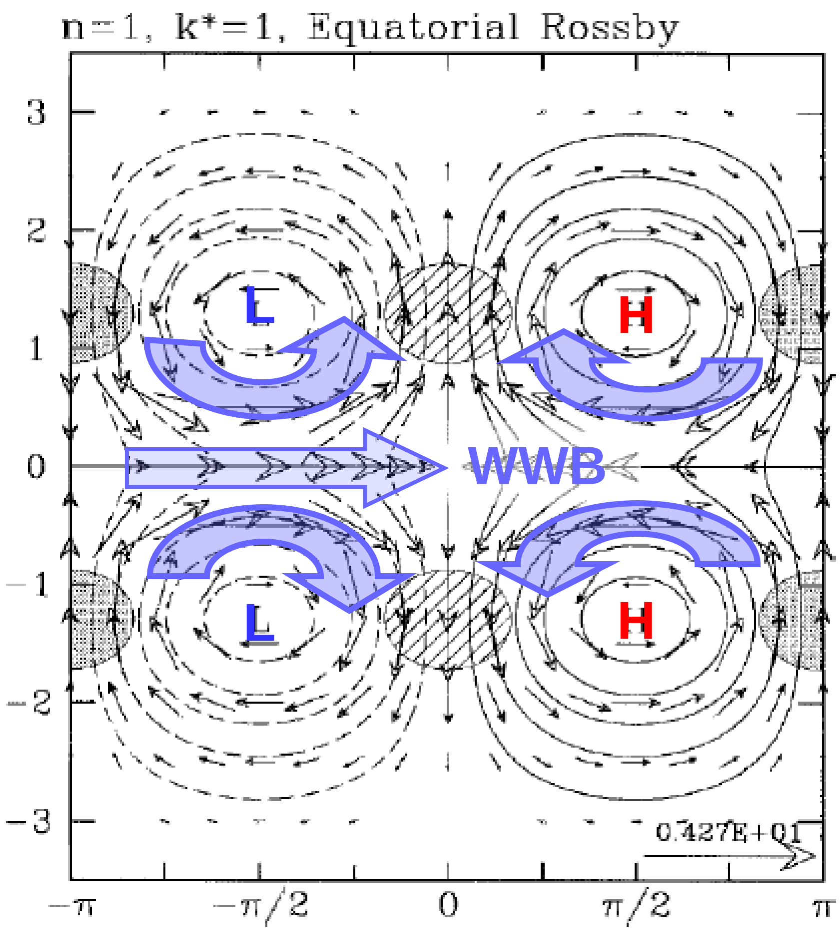
Equatorial Rossby waves



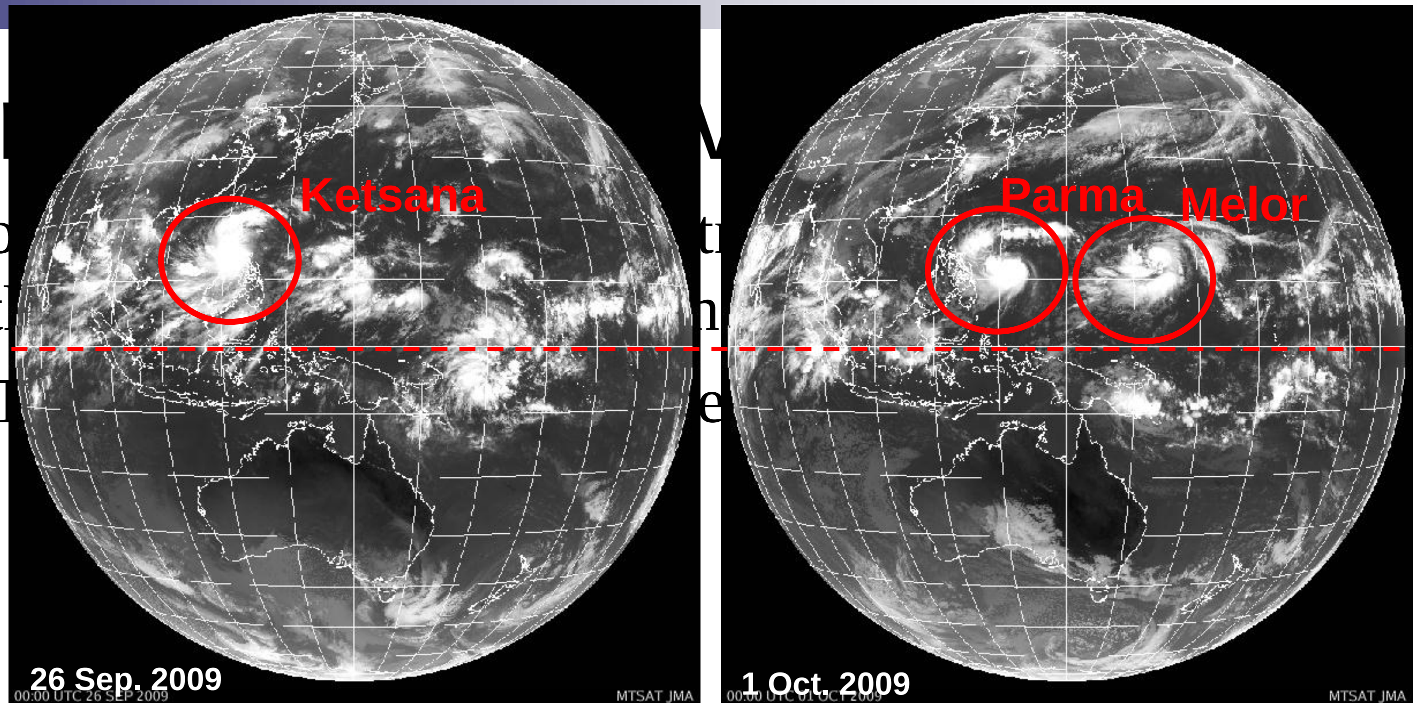
- Equatorial Rossby waves are characterized as **a pair of cyclonic/anticyclonic circulation anomalies,** and they are **equatorially symmetric**
- The flow have geostrophic balance.
- In the case of the equatorial Rossby waves, **latitudinal gradient of the Coriolis parameter** serves as a force of restitution.
- The Coriolis parameter is zero on the equator, but the latitudinal gradient is so large in the tropics, hence the equatorial Rossby waves can exist in the off-equator regions and **propagate westward**.

The theoretical equatorially trapped Rossby wave solution to the linear shallow water equations on an equatorial beta plane (Wheeler 2000, Matusno 1966)

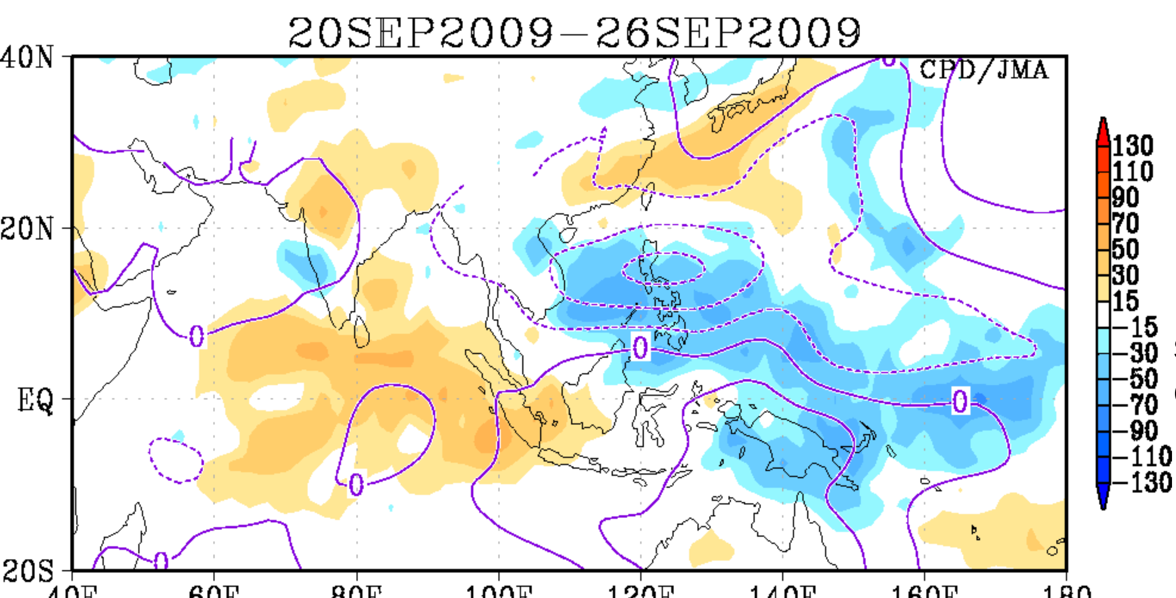
- **Westerly Wind Bursts (WWB)** are mainly generated between cyclonic anomalies.

Equator... ...W

- The develo... ...t... related to t... ...h...
- Example. T... ...e



Infrared Satellite Image by MTSAT



shade: OLR anomaly
contour: 850-hPa stream function anomaly

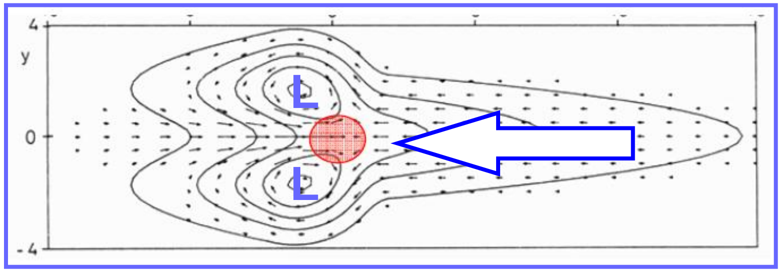
Matsuno-Gill pattern

- Both equatorial Kelvin and Rossby waves can be excited by the anomalous heating, such as latent heat release from the organized convection in the tropics.

- Gill (1980) solved the atmospheric response to the low-level heating analytically, and showed that low-level heating around the equator can excite equatorial Kelvin and Rossby waves.

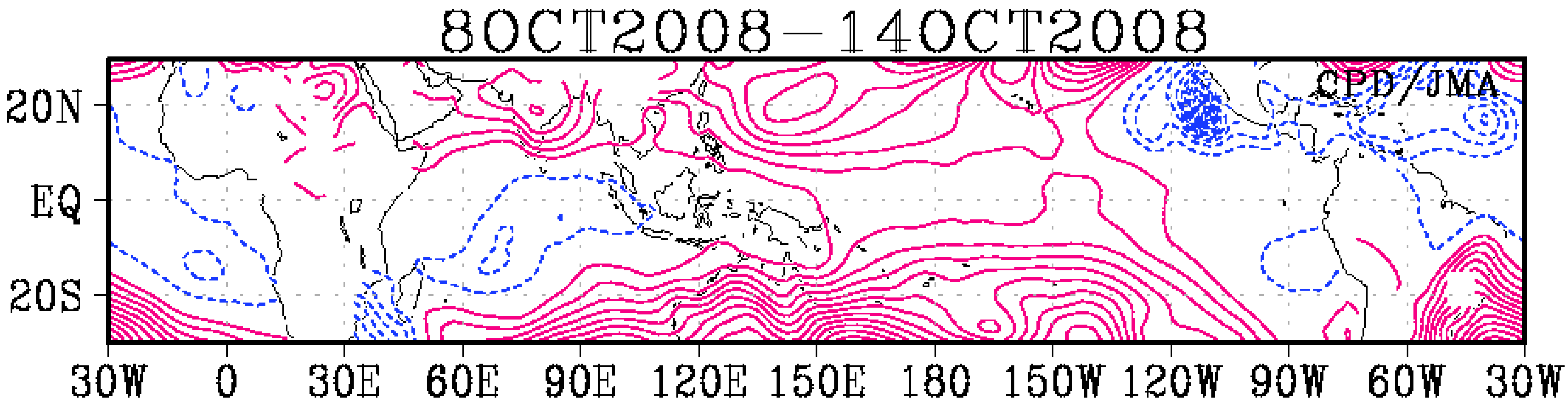
Matsuno-Gill pattern

- Observed "Matsuno-Gill pattern" in the Indian Ocean in October 2008



Gill (1980)

Cyclonic circulation anomalies in association with the equatorial Rossby waves developed and migrated to northwest/southwest in the Indian Ocean.



925-hPa geopotential height anomalies (dotted blue line shows negative height anomalies)

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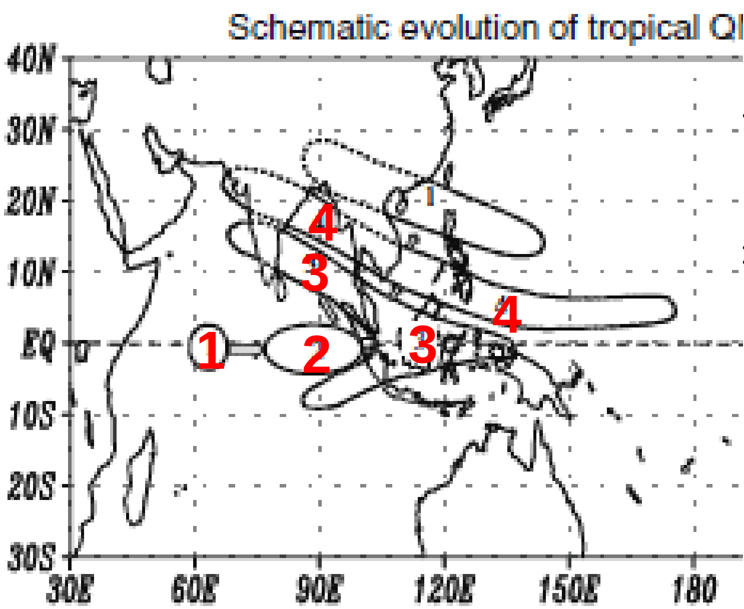
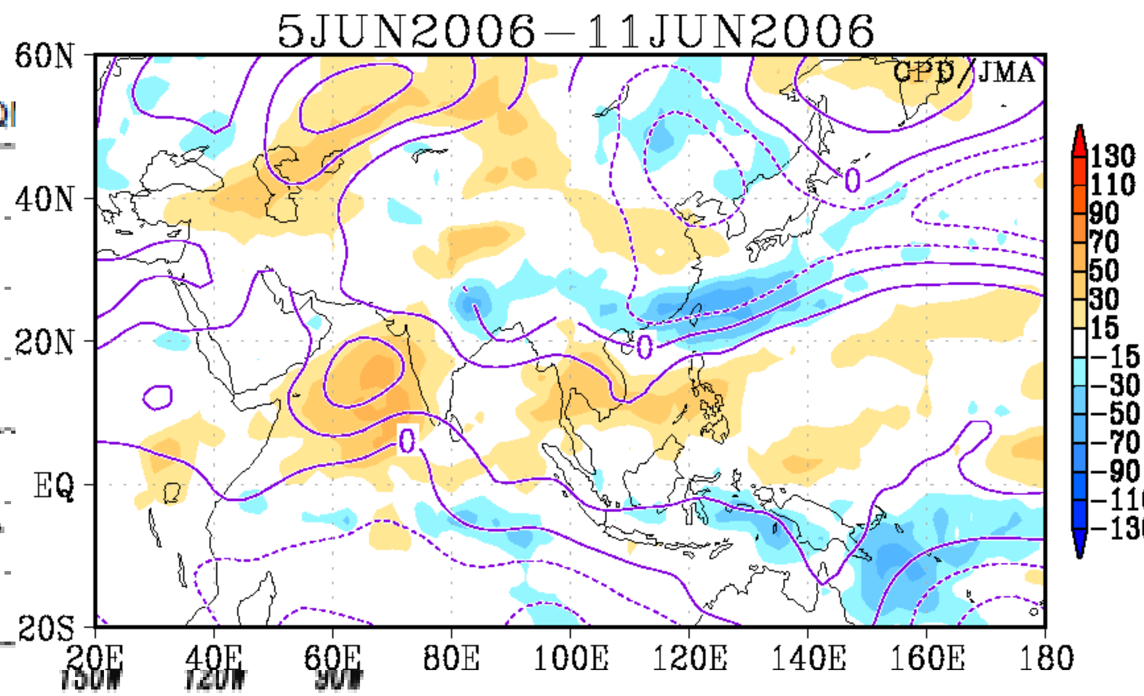
Intra-seasonal variations in the Asian Summer monsoon

Wang et. al. 2006

- Northeastward propagation of the wet/dry area and associated rainband induce quasi-monthly timescale variation of the monsoon activity.





Intra-seasonal variations in the Asian Summer monsoon (Vertical shear mechanism, Jiang et al. 2004)

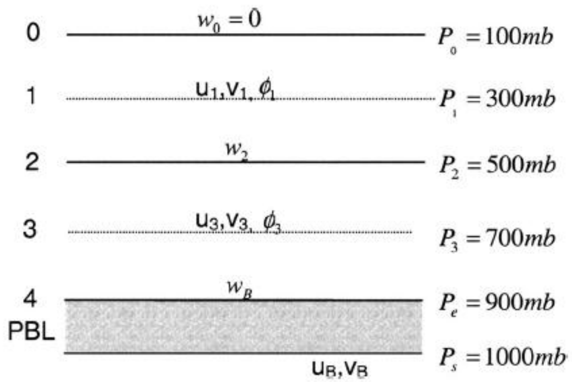


FIG. 9. Vertical structure of the 2½-layer model (Wang and Li 1993).

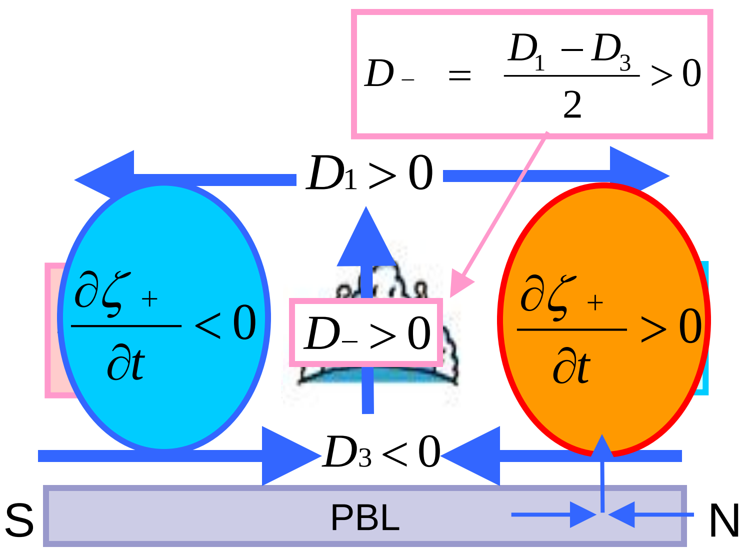
The generation of the barotropic mode in the free atmosphere can only be realized through the vertical shear of the mean flow acting on the meridional gradient of the baroclinic divergence.

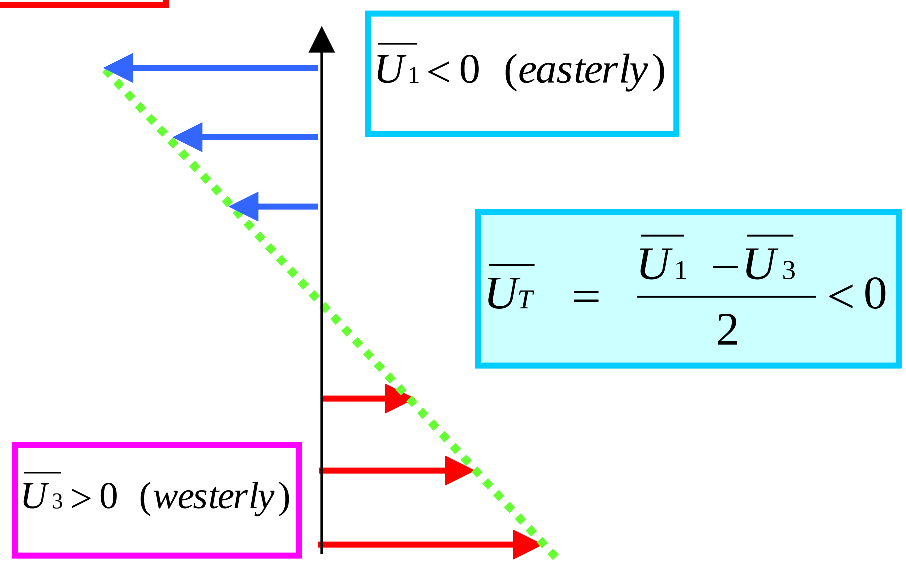
$$\frac{\partial \zeta_+}{\partial t} \propto \overline{u}_T \frac{\partial D_-}{\partial y}.$$

$$\frac{\partial D_+}{\partial t} \propto f_0 \zeta_+.$$

$$\overline{u}_T = (\overline{u}_1 - \overline{u}_3)/2$$

$$A_+ = \frac{A_1 + A_3}{2}, \qquad A_- = \frac{A_1 - A_3}{2},$$

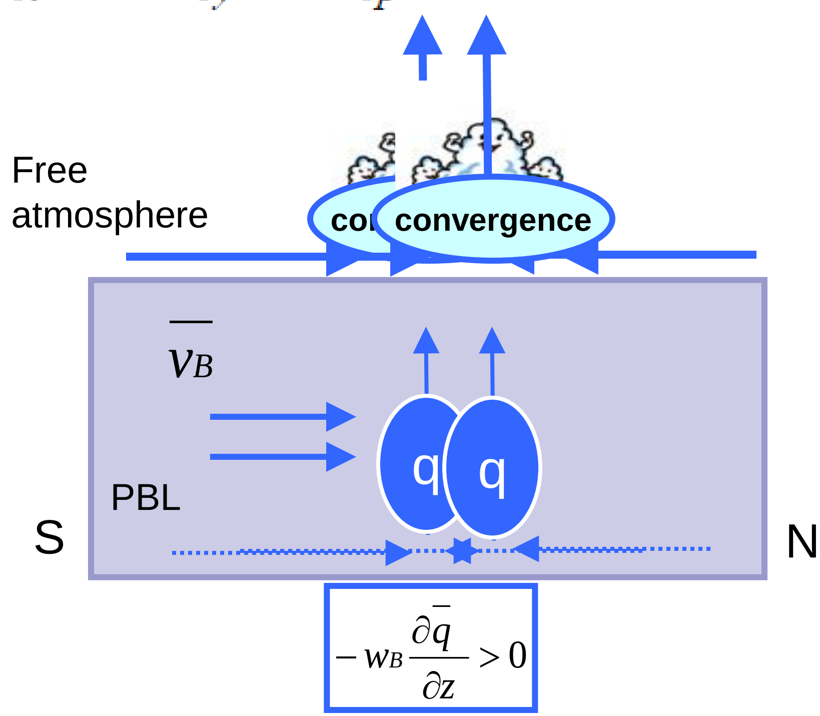




Intra-seasonal variations in the Asian Summer monsoon (Mechanism of moisture advection, Jiang et al. 2004)

The convergence at the surface level will induce the upward motion in the PBL, which will bring the rich moisture to a certain level in the PBL. The advection effect by the summer mean meridional wind in the PBL may further shift the specific humidity center to the north of convection.

$$\frac{\partial q}{\partial t} \propto -\overline{v}_B \frac{\partial q}{\partial y} - w_B \frac{\partial \overline{q}}{\partial p}.$$



Another possible mechanism that leads to the northward shift of the moisture is through the advection effect by the ISO wind in the presence of the mean meridional specific humidity.

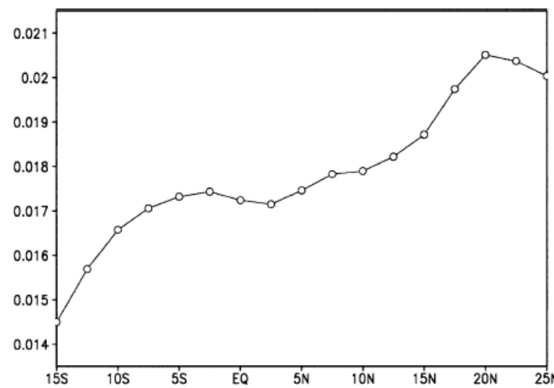
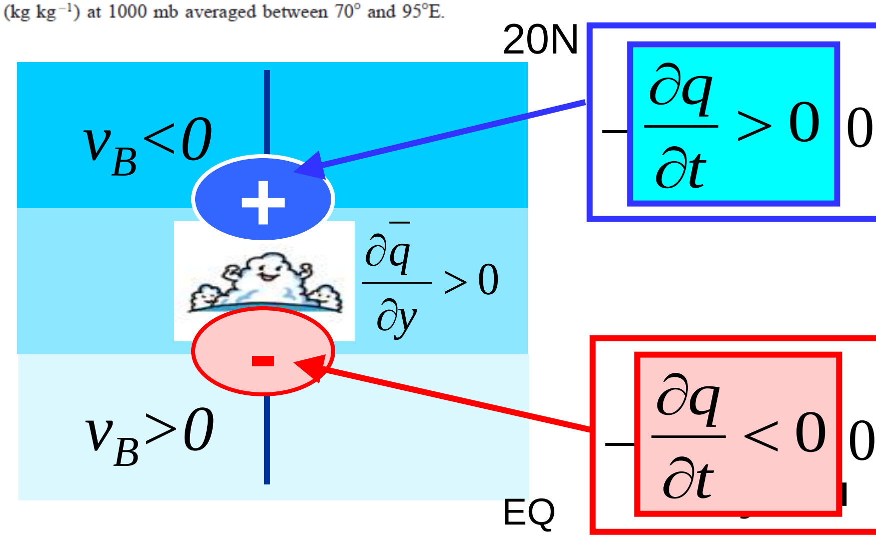


FIG. 13. Meridional profile of the summer mean specific humidity (kg kg^{-1}) at 1000 mb averaged between 70° and 95°E.

$$\frac{\partial q}{\partial t} \propto -v_B \frac{\partial \overline{q}}{\partial y}.$$



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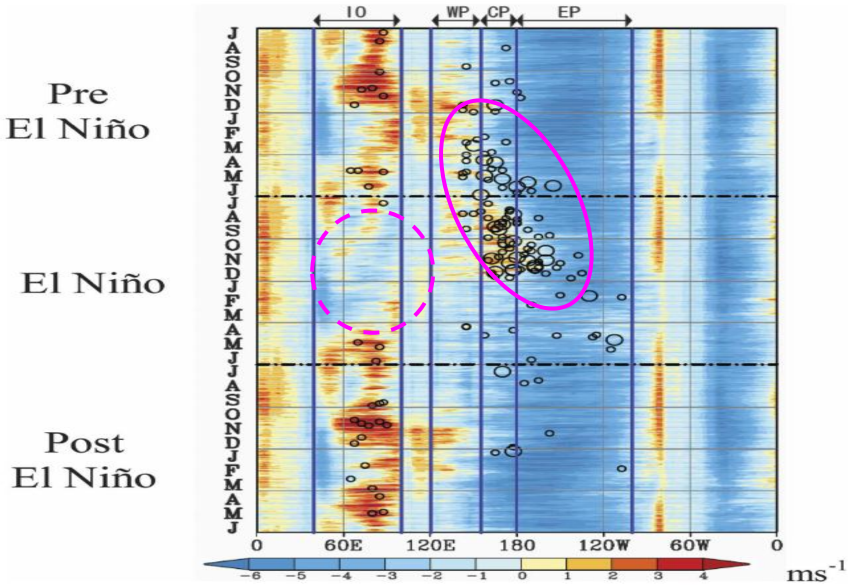
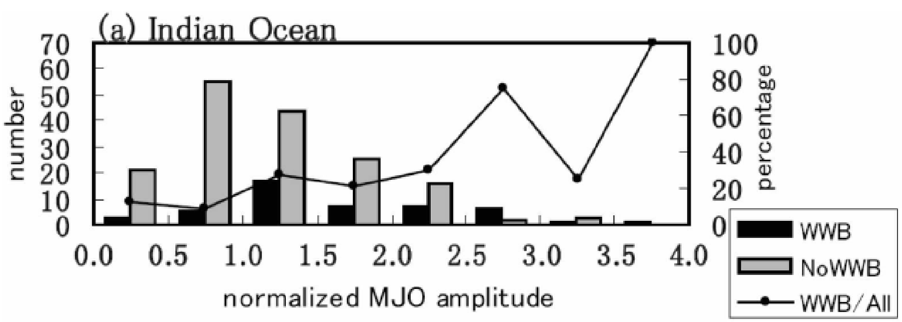
Interaction between different scale variations

- ENSO, MJO and WWB



WWBs were frequently observed in the western Pacific before the mature El Niño. The seasonality of WWBs depends on the interannual variations both in the Pacific and the Indian Ocean.

Time-longitude cross section of 850-hPa zonal wind anomalies along the equator (color) and WWBs (circle)



The strong MJO amplitude is a favorable condition, but not a sufficient condition for WWB generation.

Histogram of the event number of WWBs for MJO amplitude

Seiki and Takayabu (2007a)

Summary

In this lecture, we have overviewed the tropical variations with the intraseasonal timescale.

- **MJO** …. Eastward propagation,
  about 40-50 days/cycle (slower than Kelvin wave)
  When the MJO reaches the Indian Ocean or the Pacific Ocean,
  the Kelvin wave and the Rossby wave tend to develop in the region.

- **Kelvin wave** …. Eastward propagation,
  5-20 days/cycle (faster than MJO)

- **Rossby wave** …. Westward propagation,
  30 days/cycle,
  Closely related to the development of the tropical cyclones
  and the westerly wind bursts !

- **Intra-seasonal variations in the Asian summer monsoon** ….
  For the northeastward propagation of the wet/dry area, vertical shear of the mean flow and the mean specific humidity gradient are important.

For more valuable climate information…

- Continuous observations/monitoring are very important.
  - The data accumulation is essential for the more comprehensive understanding of the tropical climate/weather variations.
- Evaluate the local impact of the ENSO, the MJO and so on…
  - To provide the clear-cut information, it is needed to summarize the local impact of the variations.
- Update the knowledge with recent studies.
  - The study on tropical circulation is constantly advancing field.

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- Interactions and so on…

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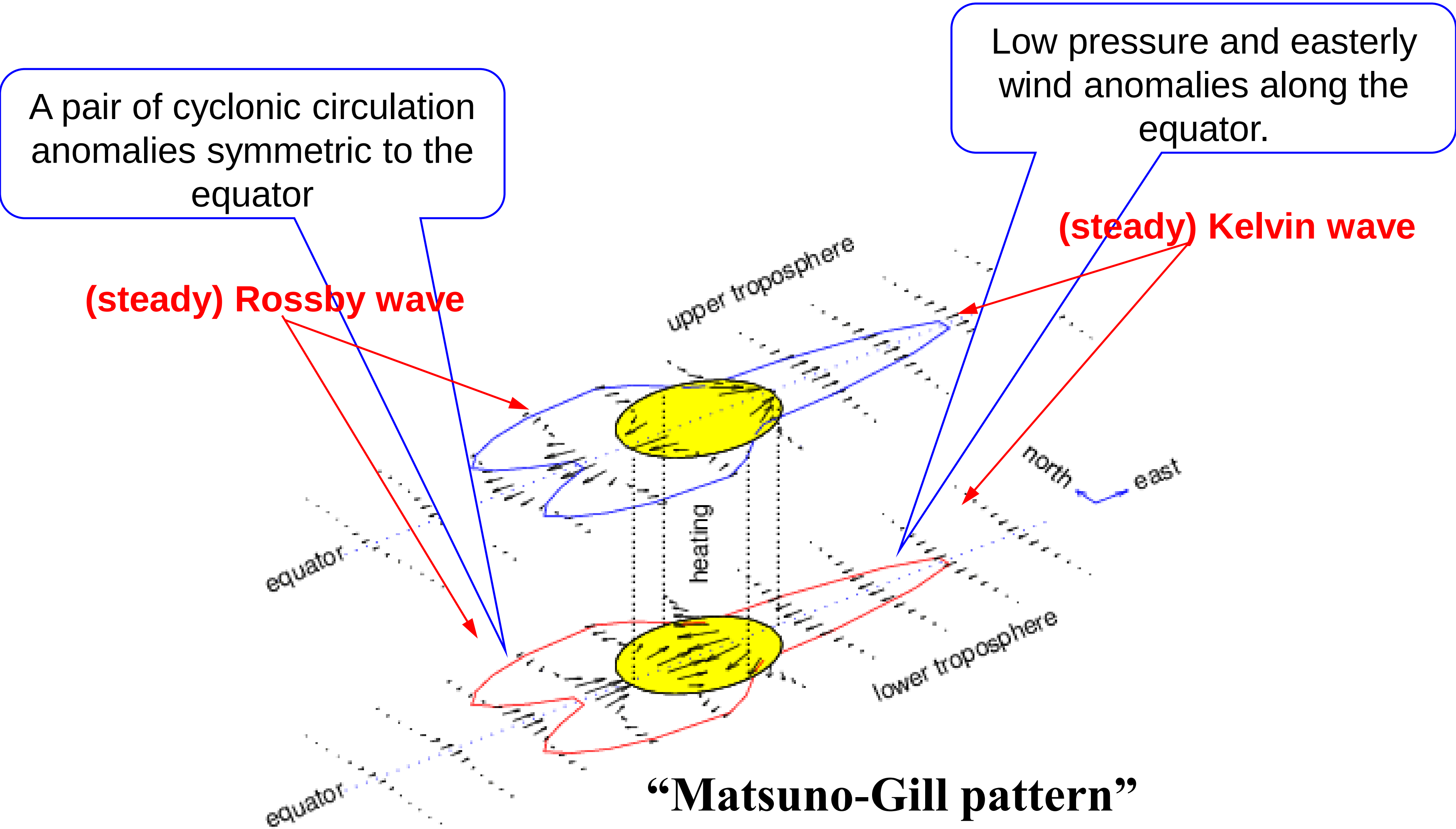
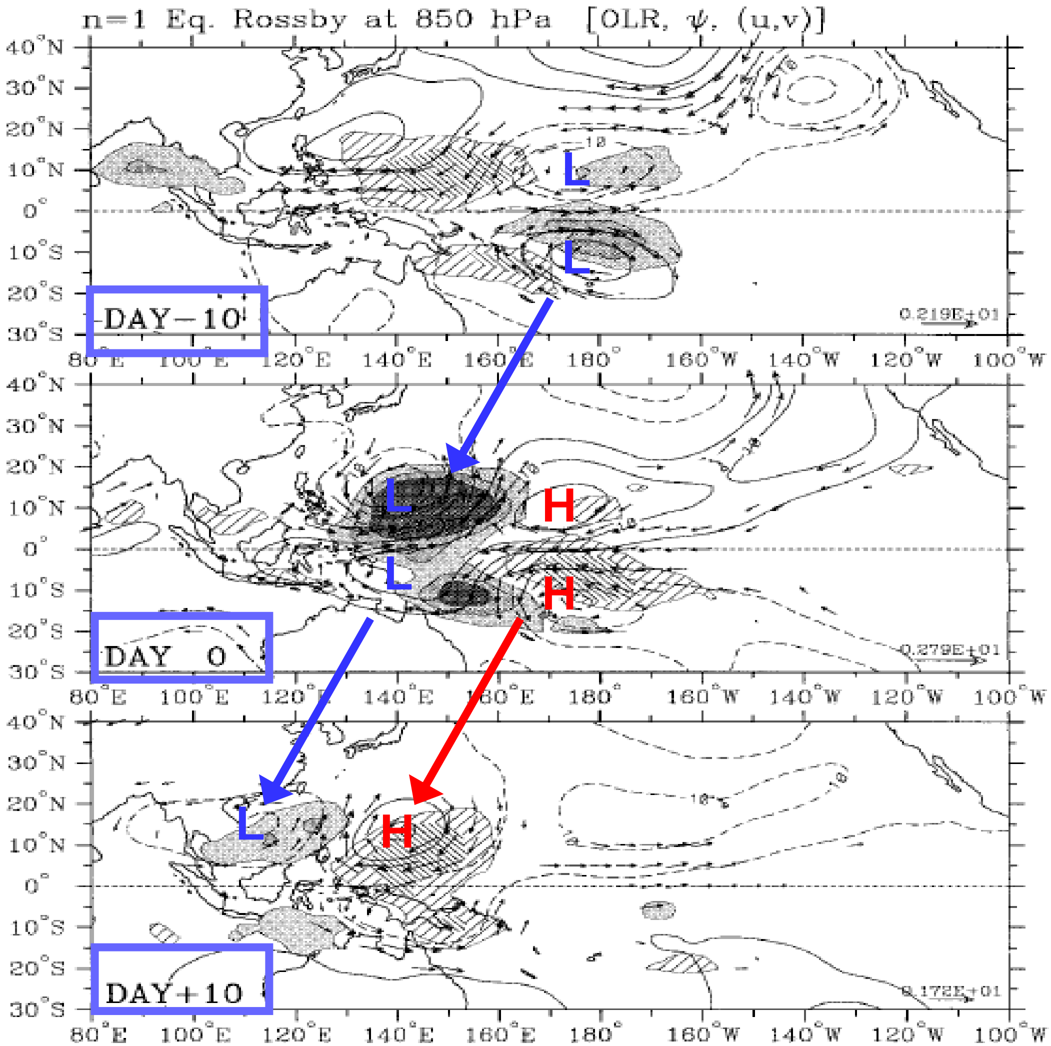
Thank you for your attention!

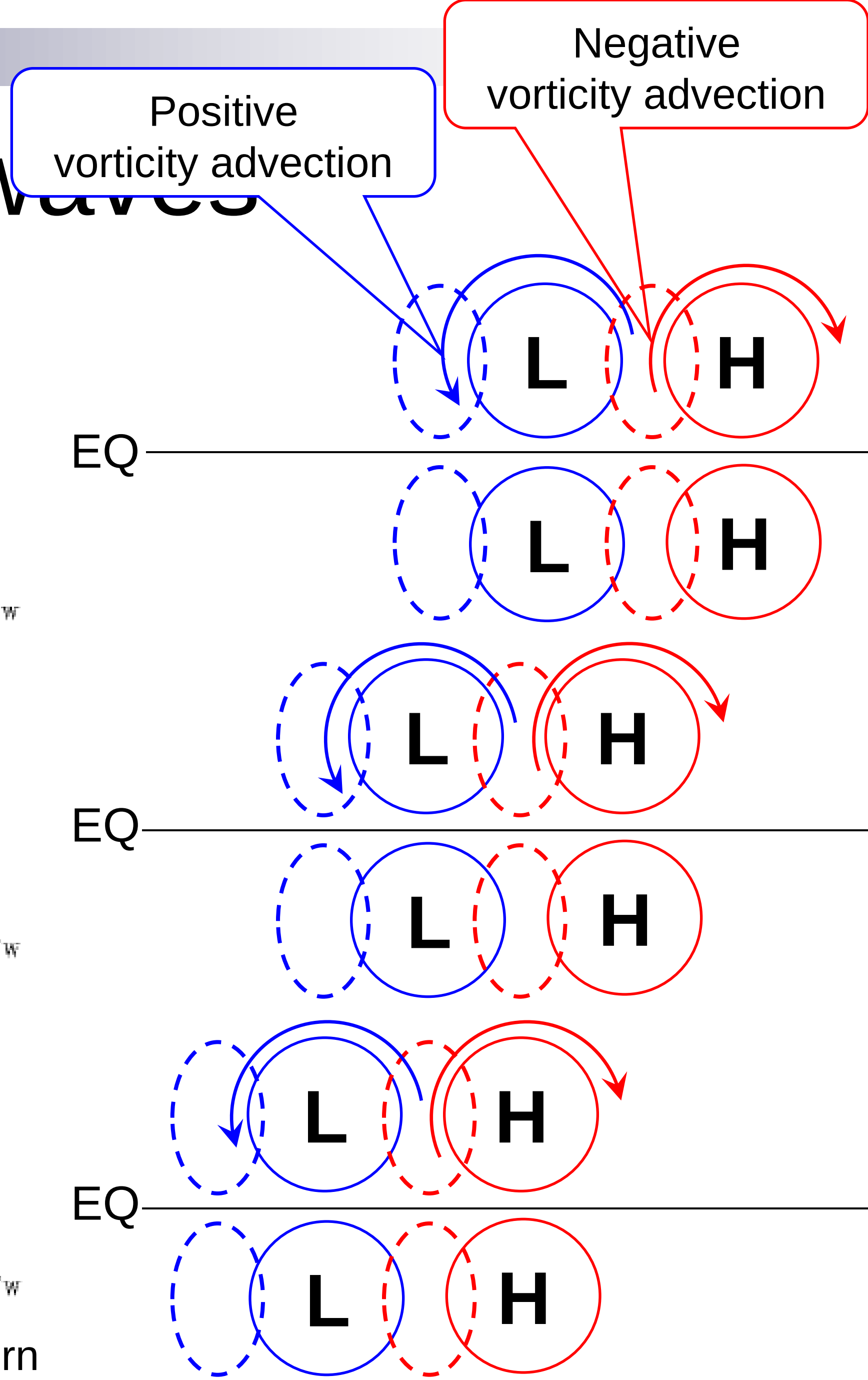
Matsuno-Gill pattern



Gill (1980), see also Matsuno (1966) and Webster (1972)

Equatorial Rossby waves



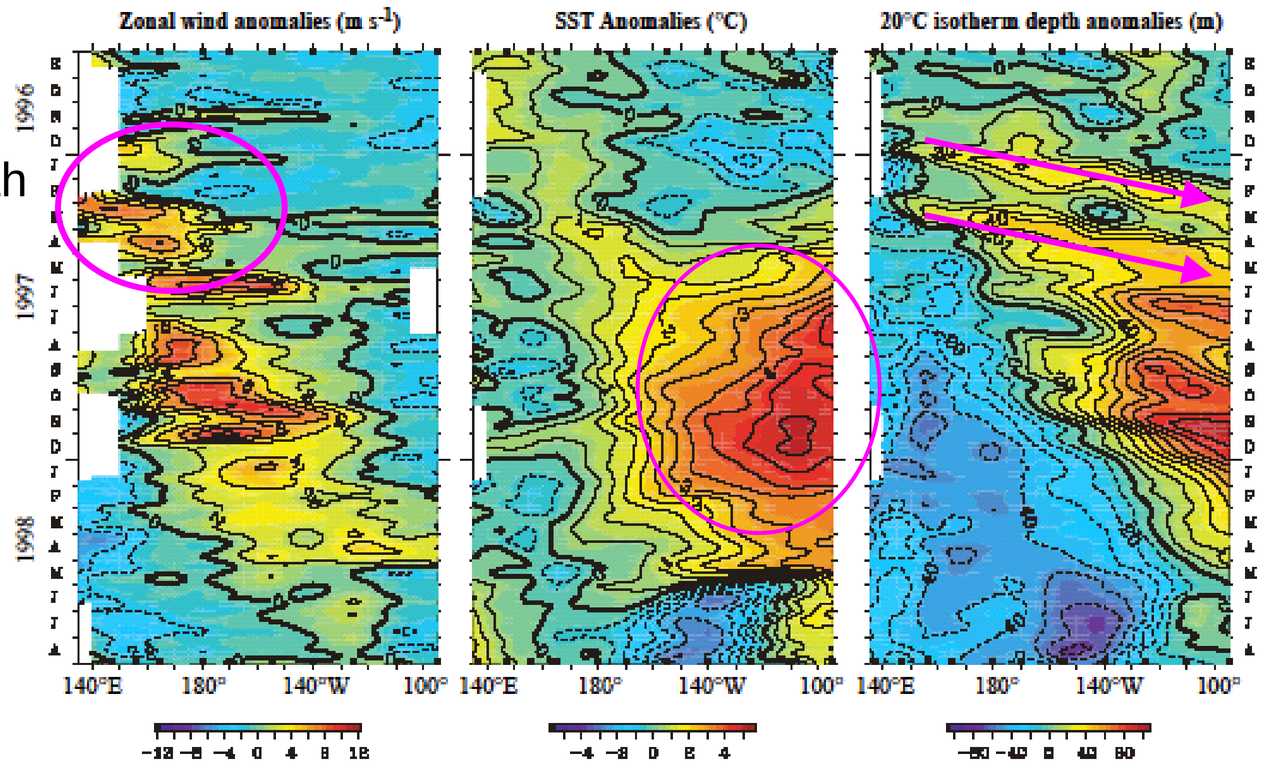


Regression map for the convective peak in the western Pacific (Wheeler et al. 2000)

Interaction between different scale variations

- MJO and El Niño

WWBs with the MJO

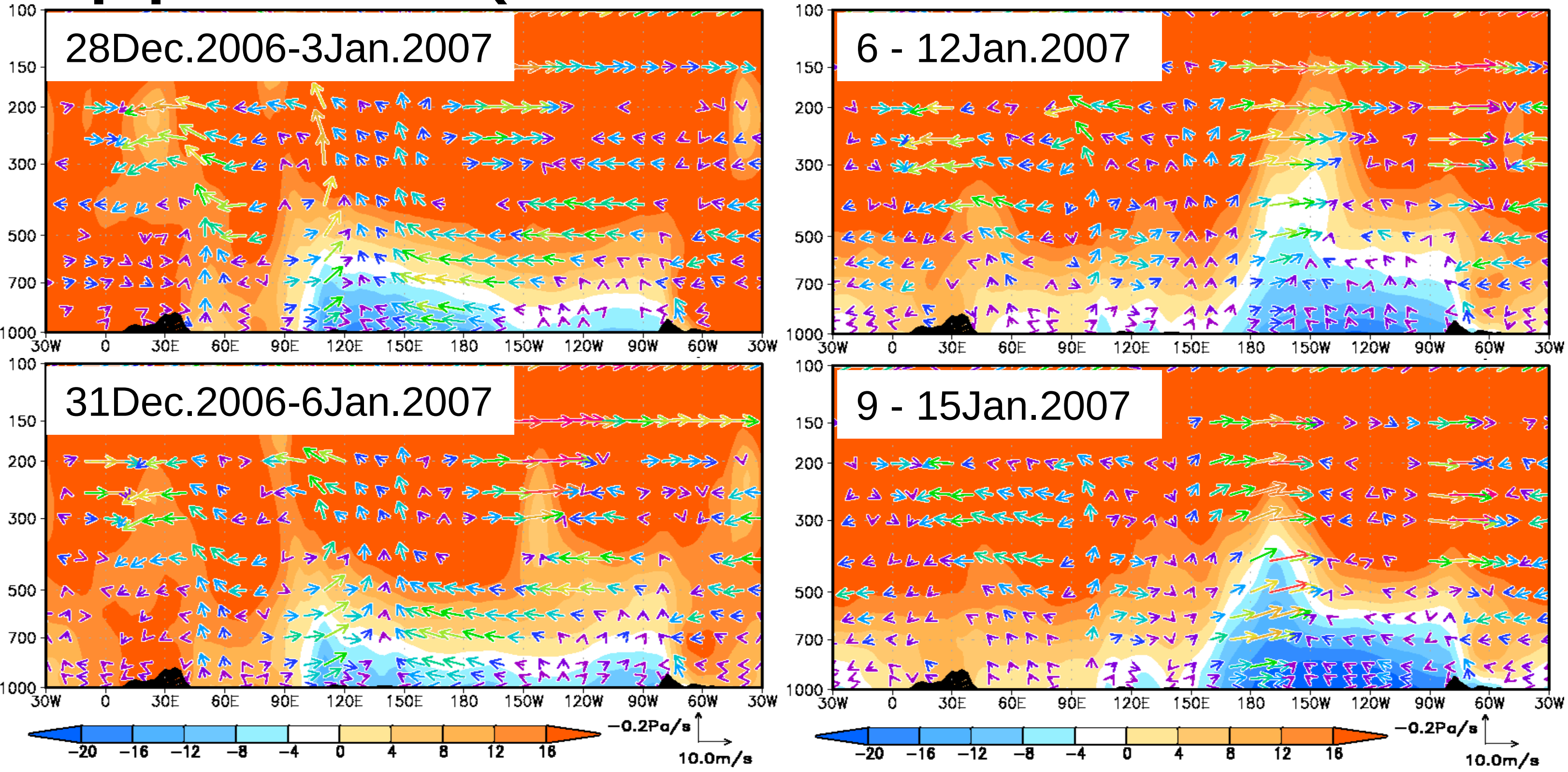


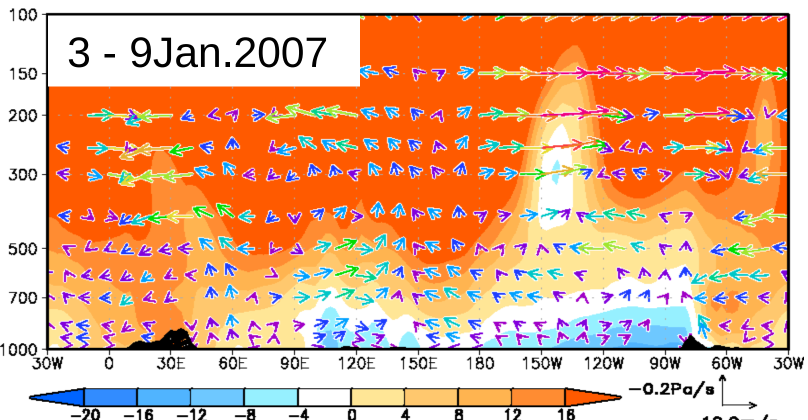
Warm Kelvin waves in the equatorial Pacific

Time-longitude cross sections of anomalies in (left) surface zonal wind, (middle) SST and (right) 20ºC isotherm depth.

McPhaden (1999)

Appendix (related to slide 12 in 1Dec2009 lecture by Y.Harada)



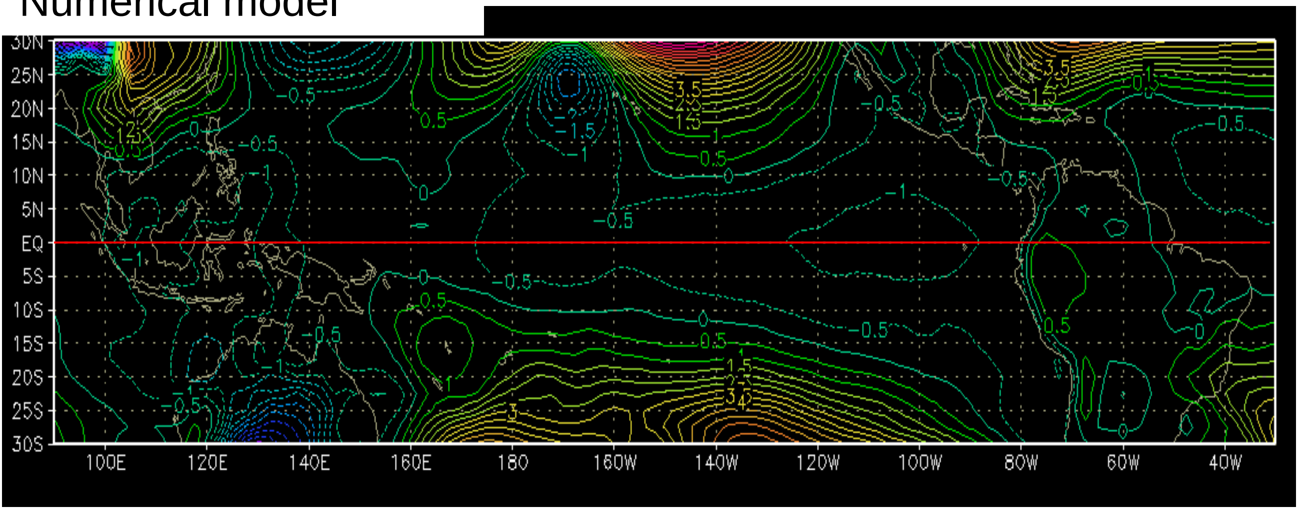


Longitude-height cross section of zonal wind & pressure velocity (vector), geopotential height anomalies (shading)

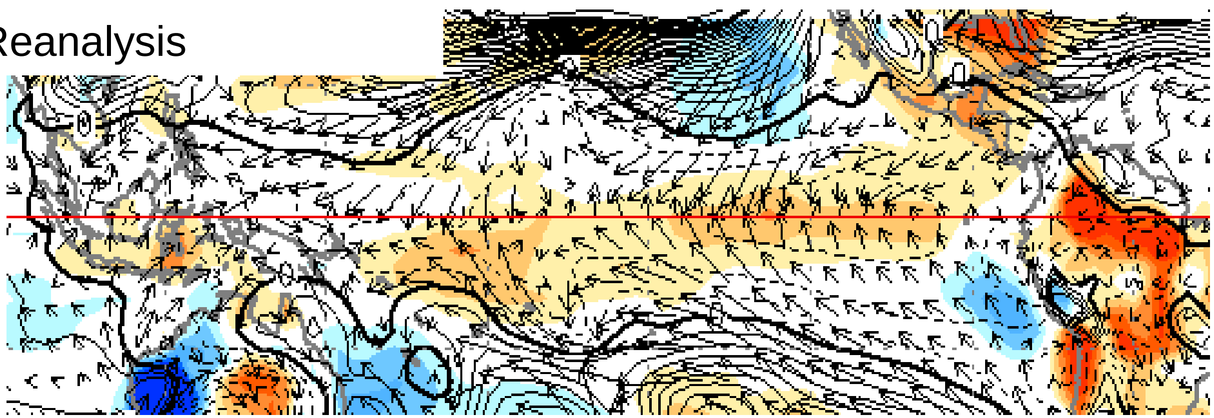
Negative anomalies can not propagate eastwards, and accumulate to the east of South America.

Comparison with numerical model for 1month forecast

Numerical model



Reanalysis



In the numerical model, low pressure anomalies accumulate to the east of South America, and migrate towards extra-tropical regions.

3 – 12 January 2006 mean sea level pressure anomalies (contour)