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Mid-latitude - MJO teleconnection over East Asia in the Northern winter

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Midlatitude-MJO teleconnection over East Asia in Northern Winter

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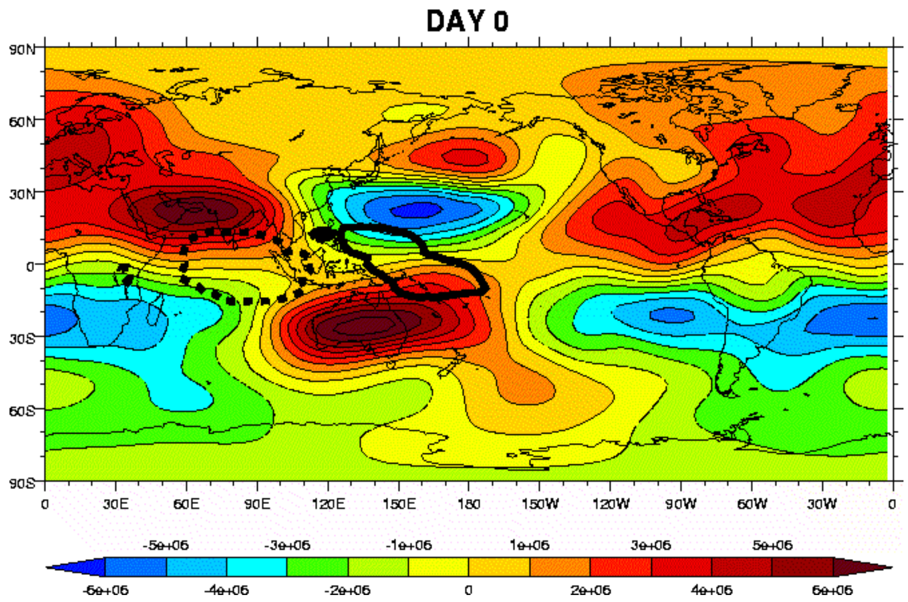
MJO, a view from global aspect

•During the MJO event, subseasonal fluctuations are global in extent.

•Among the features, conspicuously, the four-cell structure of MJO dominates the subtropical MJO anomaly.

•Notably, North-South dipole (shown below) appears in the mid Pacific [*Liebmann and Hartmann* 1984; *Weickmann et al.* 1985].

•Recently, Mori and Watanabe (2008) showed that MJO-teleconnection explains about 30% of PNA variability in subseasonal frequency band.



Motivation of this study

- Consonant behavior of midlatitude anomaly during MJO life-cycle has been noted [*Ferranti et al.* 1990; *Blade and Hartmann* 1996; *Mathews* 2004].

- Most studies address equatorial wave source (Rossby Wave Source) as a possible cause for this connection.

- Considering down stream, bow-like propagation of Rossby wave forced by heating, the western Hemispheric teleconnection is likely and plausible. However, the actual teleconnection is most significant over upstream of the source, i.e. East-Asia. Why?

- Over down stream, extreme precipitation in U.S [*Mo and Higgins*, 1998; *Jones*, 2000; *Bond and Vecchi*, 2003], South American precipitation [*Paegle et al*. 2000], and temperature in northern high latitudes [*Vecchi and Bond*, 2004] are shown to be related with MJO.

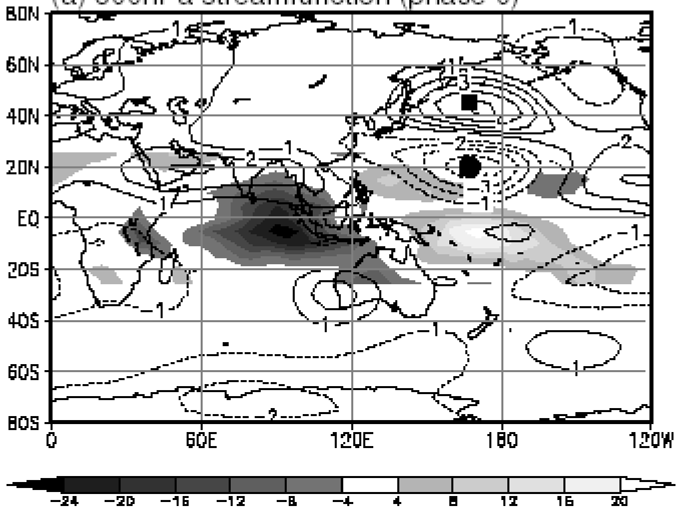
- Then, what happens in East-Asia, during the MJO life-cycle?

MJO-Teleconnection Pattern

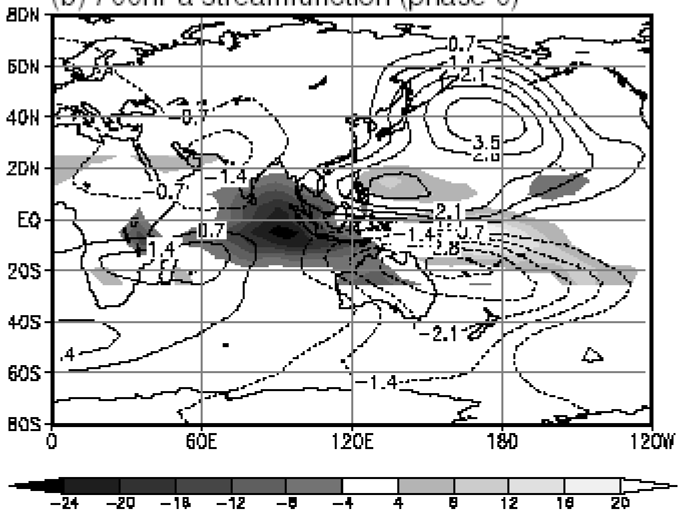
Streamfunction

Divergence, Pressure Velocity

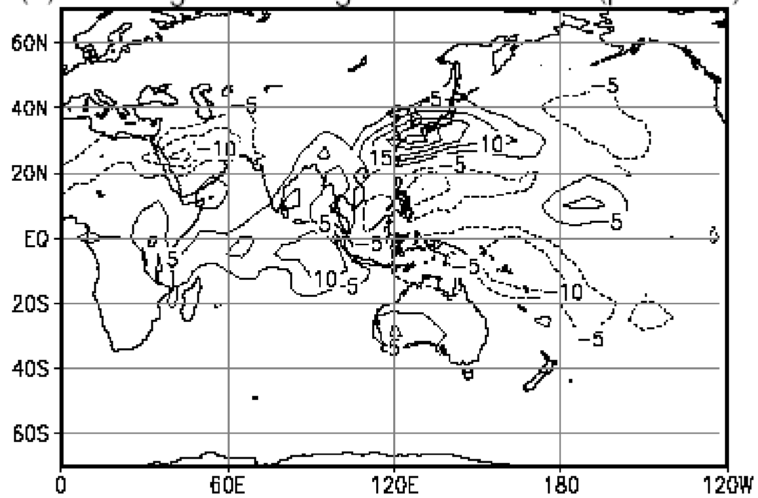
(a) 300hPa streamfunction (phase 0)



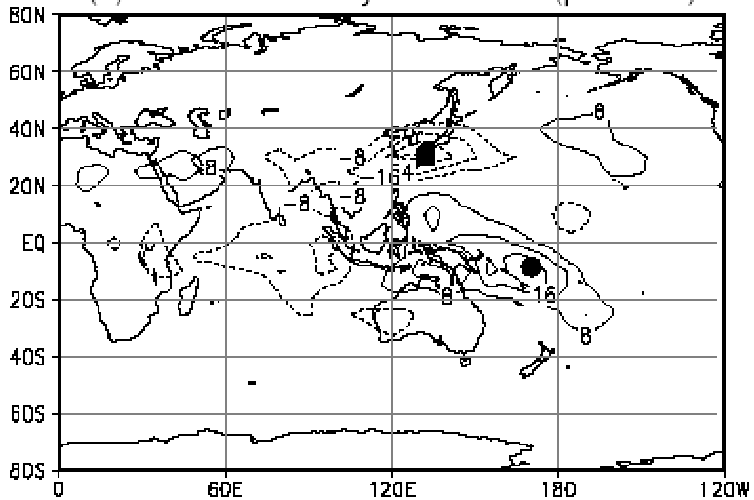
(b) 700hPa streamfunction (phase 0)



(a) Convergence/divergence at 200-hPa (phase -2)



(b) Pressure velocity at 300-hPa (phase -2)



Role of Mean State on the Teleconnection

Modelling MJO-Teleconnection

- Can we (basically) regard the observed teleconnection as forced linear response of tropical MJO heating on a given basic state?

- We approached this question using linear baroclinic model with prescribed tropical heating.

- Spectral Core (Flexible Modelling System, GFDL) is used for the modelling study.

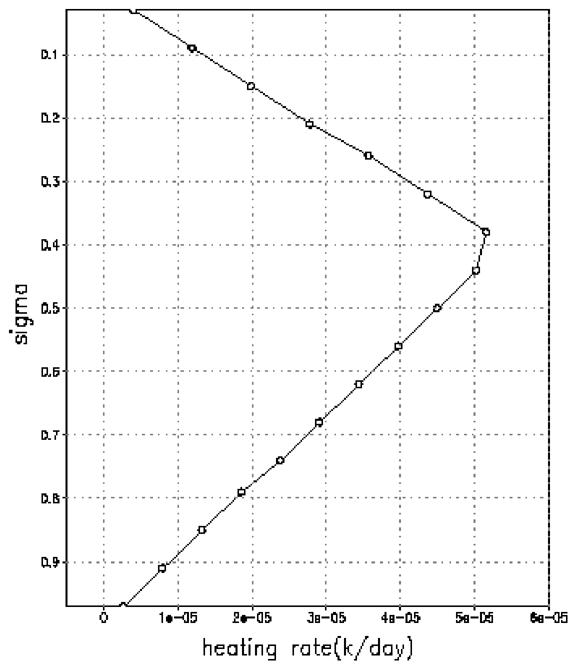
- To examine the linear response of specified tropical heating, we linearized code and incorporated the explicit heating term on the thermodynamic part of the model equation.

- Rayleigh friction and Newtonian cooling are applied following Jin [1996].

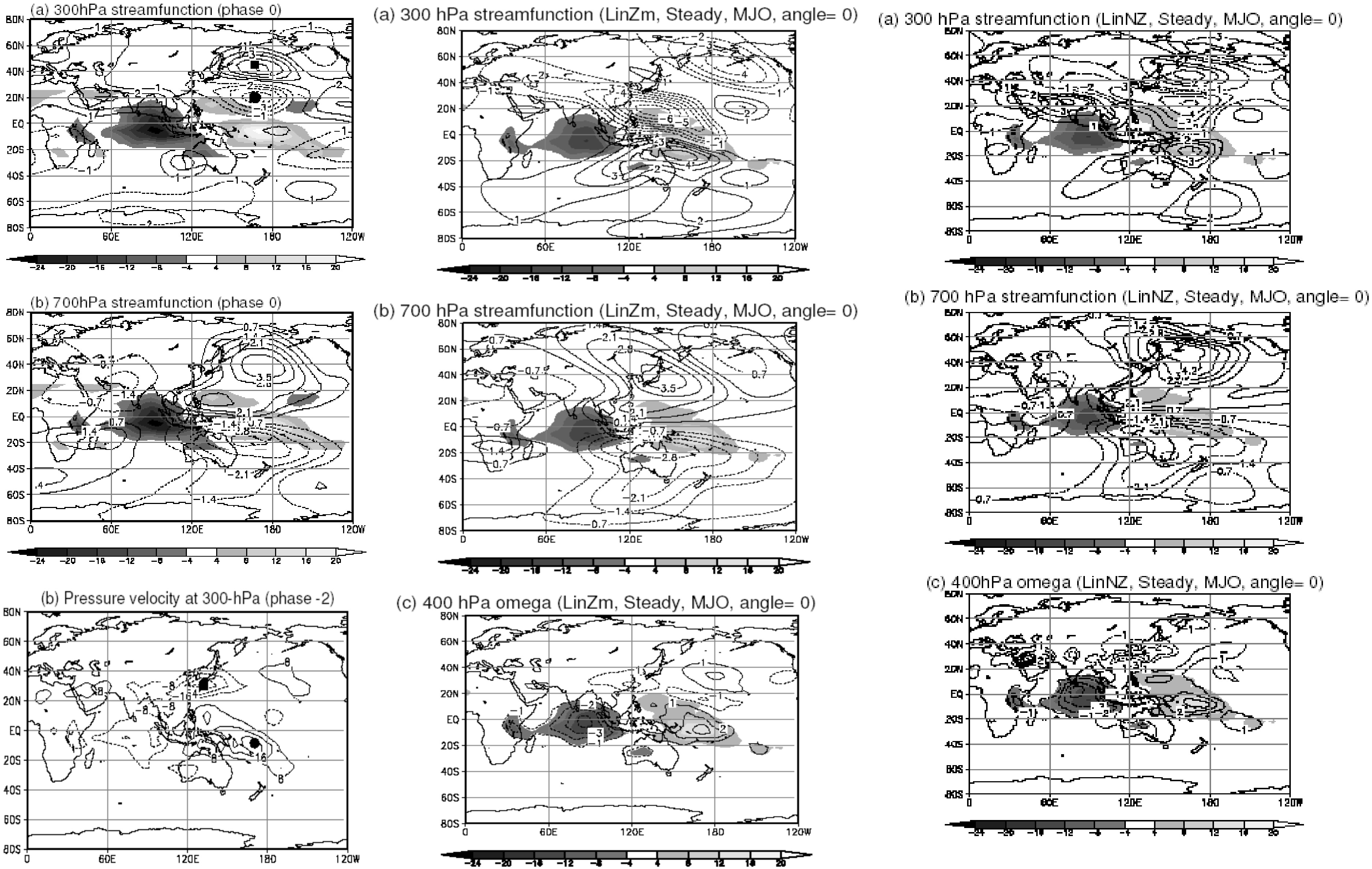
Experiment Setup

Experiment Option		1	2	3	4
Heating Type	Single	√			
	Dipole		√		
	OLR			√	√
Basic State	Rest Atm.	√	√		
	Zonal Mean			√	
	Non-Zonal				√

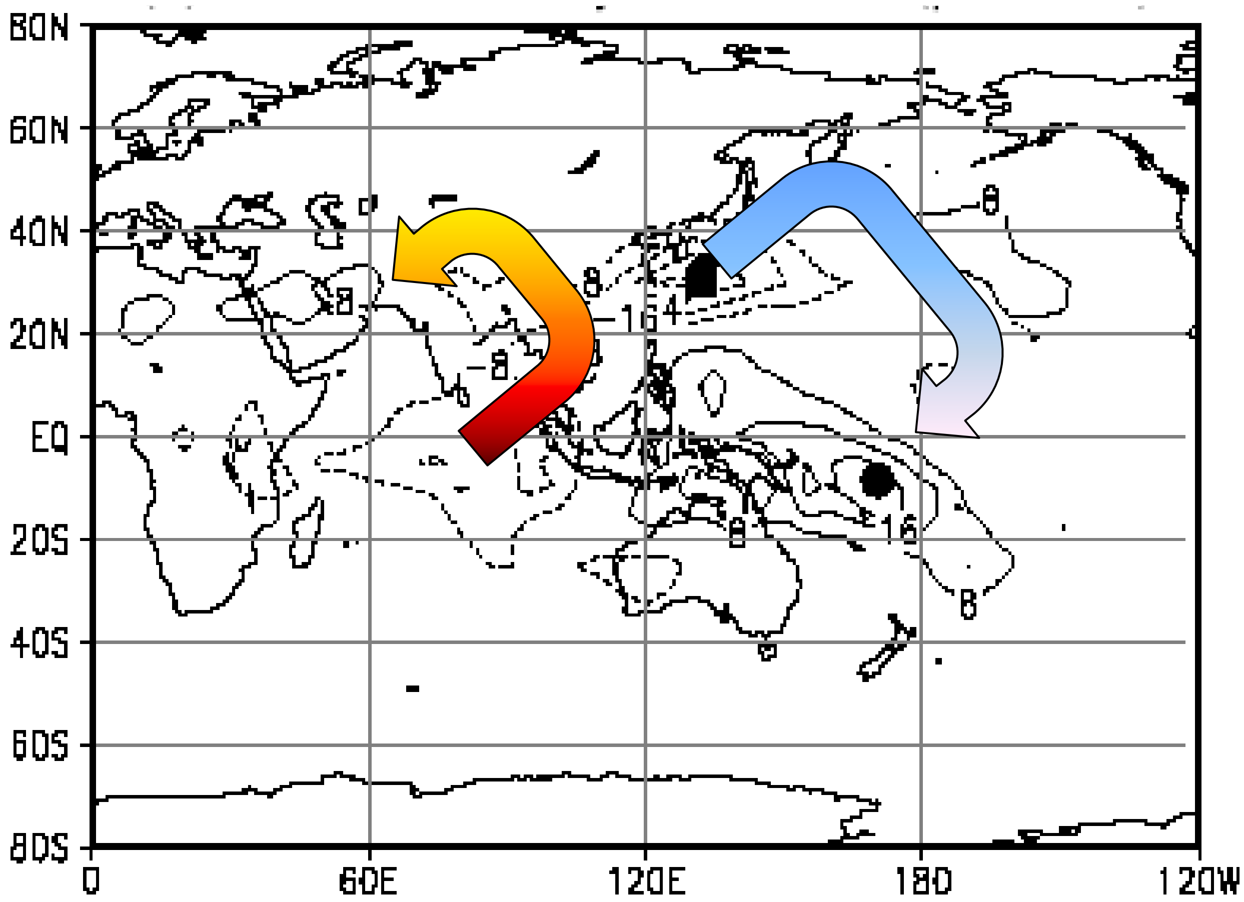
Vertical Heating Structure



Regression | Exp 3, OLR, Zonal | Exp 4, OLR, Non Zonal



Local Hadley Circulation?



Generalized Omega Equation

$$L_1(\omega) + L_2(\omega) = \quad F_{QG} + F_{Heating}$$

$$L_1(\omega) = \quad \nabla^2 \left(\bar{\sigma}\omega\right) + f^2 \frac{\partial^2 \omega}{\partial p^2}$$

: 3D-laplacian of omega

$$L_2(\omega) = f \frac{\partial}{\partial p} \left(\bar{\zeta}\nabla^2 \chi\right) - f \frac{\partial}{\partial p} \left(\omega \frac{\partial \bar{\zeta}}{\partial p}\right) - f \frac{\partial}{\partial p} \left(\nabla \omega \cdot \nabla \frac{\partial \bar{\psi}}{\partial p}\right)$$
$$+ f \frac{\partial}{\partial p} \left(\nabla \chi \cdot \nabla(\bar{\zeta} + f)\right) + \bar{\pi}\nabla^2 \left(\nabla \chi \cdot \nabla \bar{\theta}\right) \ ,$$

:A collection of internal processes not pertained to balanced dynamics

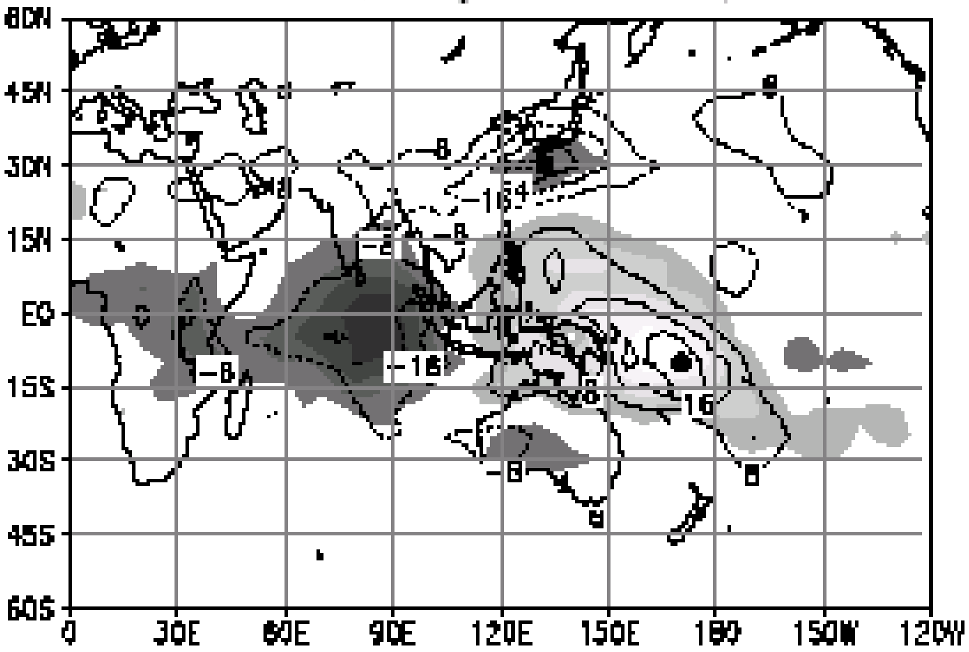
Forcings

$$F_{QG} = \underbrace{f\frac{\partial}{\partial p}J(\bar{\psi},\zeta) + f\frac{\partial}{\partial p}J(\psi,\bar{\zeta}+f)}_{\text{Differential Vorticity Advection}} + \underbrace{\bar{\pi}\nabla^2 J(\bar{\psi},\theta) + \bar{\pi}\nabla^2 J(\psi,\bar{\theta})}_{\text{Temperature Advection}}$$

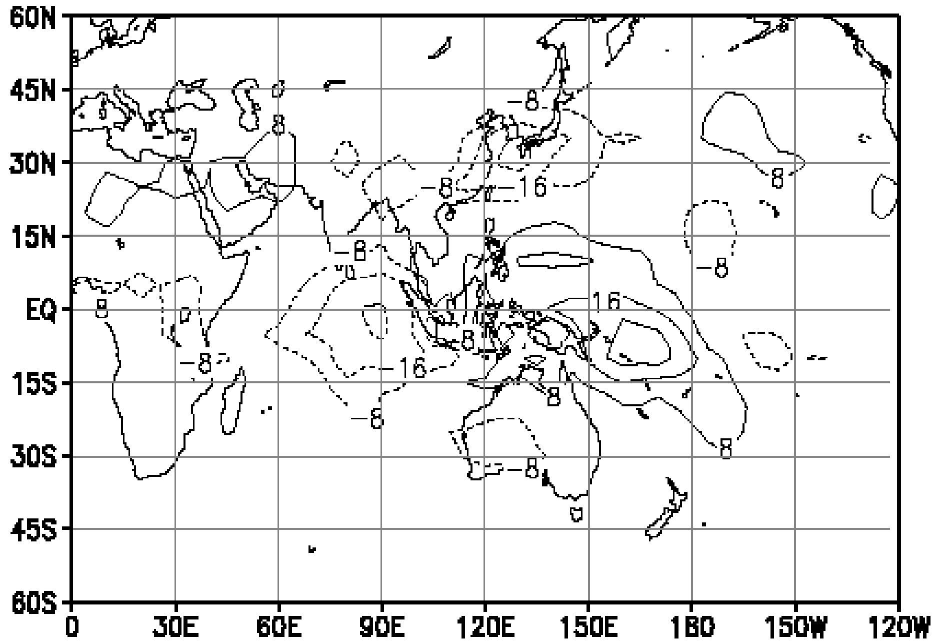
$$F_{Heating} = \underbrace{-\frac{R}{P}\nabla^2\left(\frac{Q}{c_p}\right)}_{\text{Effect of latent heating by large-scale convection}}$$

Analysis VS. Total Solution

ω from regression (300hPa)

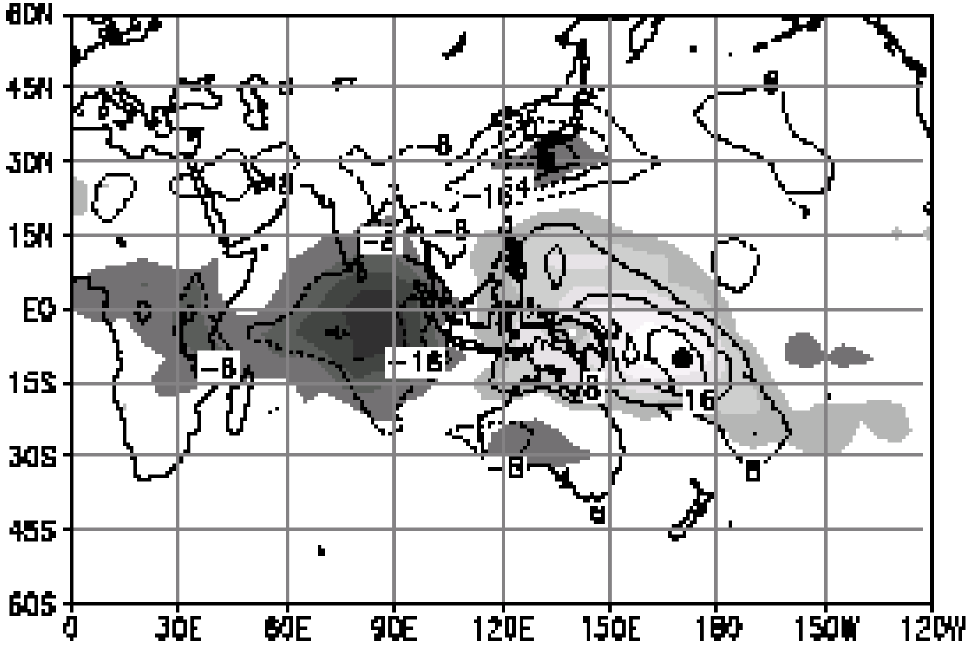


ω^* from SOR (300hPa)

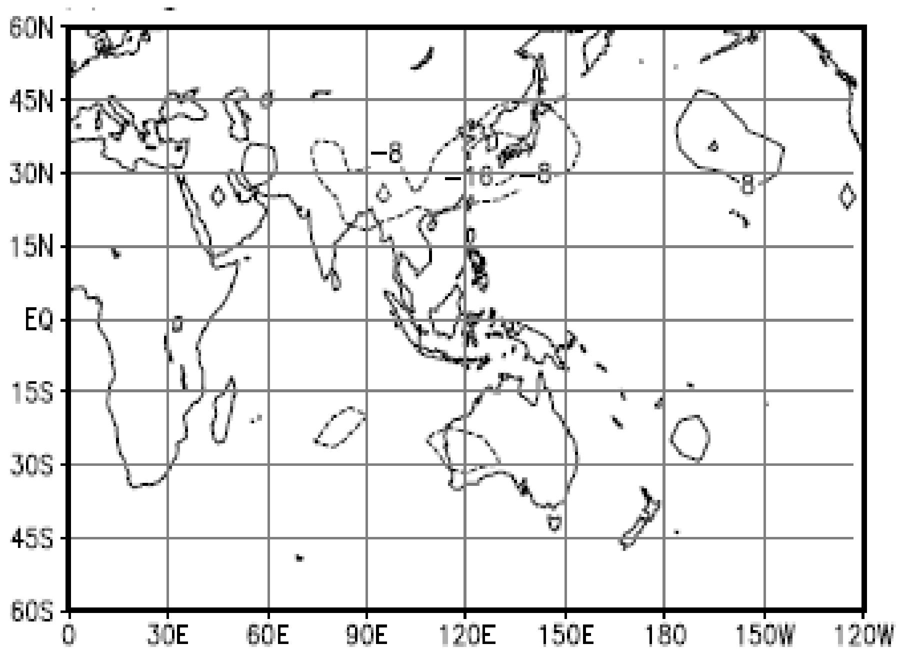


Analysis VS. QG Solution

ω from regression (300hPa)



ω from QG forcing (300hPa)

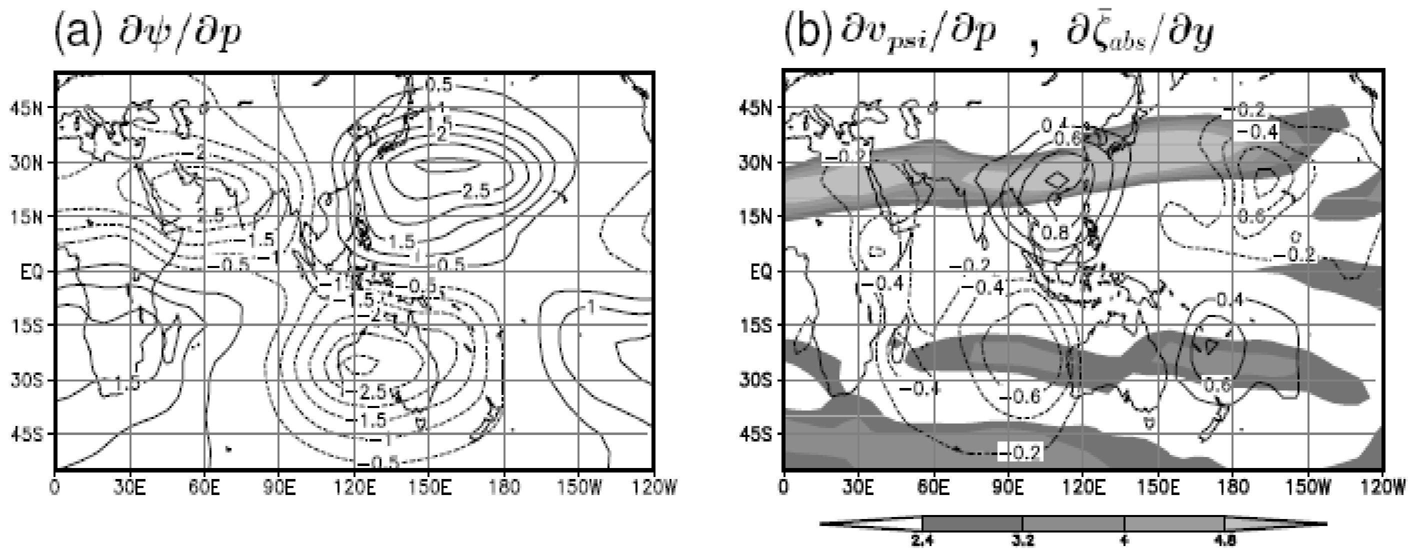


Interpretation of QG forcing

•Vertical motion from QG forcing is largely explained by the second QG forcing term.

•Second QG forcing term:

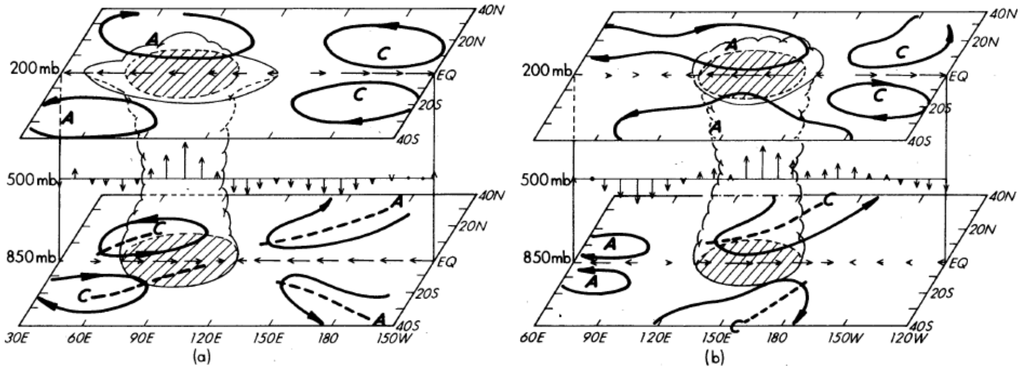
$$f\frac{\partial}{\partial p}J(\psi,\bar{\zeta}+f) = f\frac{\partial}{\partial p}\left[u_\psi\frac{\partial}{\partial x}(\bar{\zeta}+f) + v_\psi\frac{\partial}{\partial y}(\bar{\zeta}+f)\right] \simeq f\frac{\partial v_\psi}{\partial p}\frac{\partial\bar{\zeta}_a}{\partial y}$$



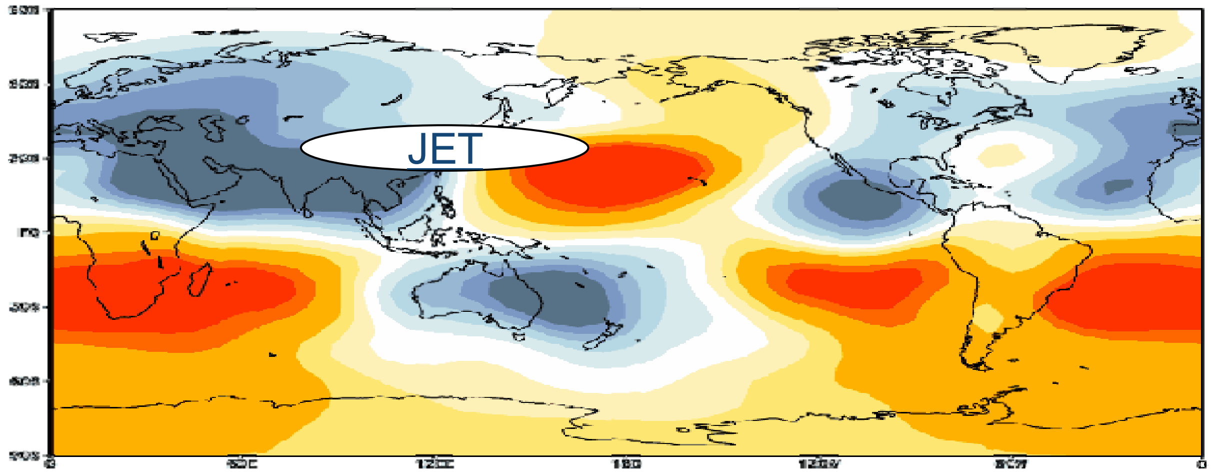
Interpretation of QG forcing

Typical composite circulation picture

(From Rui and Wang, 1990)



Baroclinic stream function regressed on MJO



Coincidence of Jet and Vertical Motion

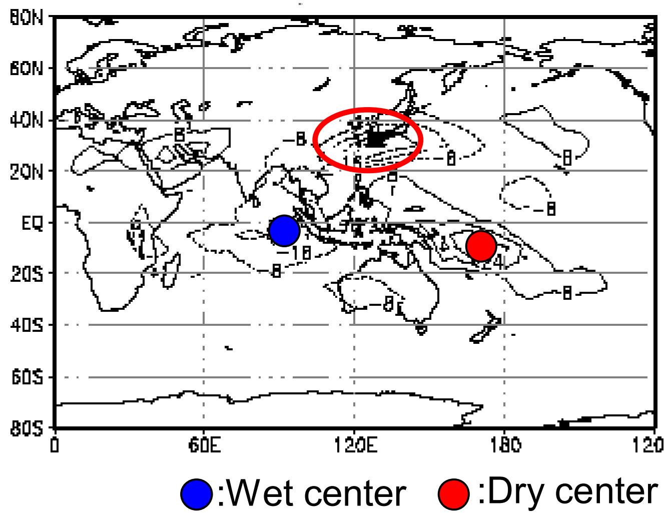
•In some phase of MJO, local maxima of **wintertime Asian jet** and the **vertical velocity induced by MJO** coincides.

•When this happens, the vertical vorticity advection and tilting terms can be big.

•Usually, the two terms are neglected in QG-theory [*Lorenz* 1963].

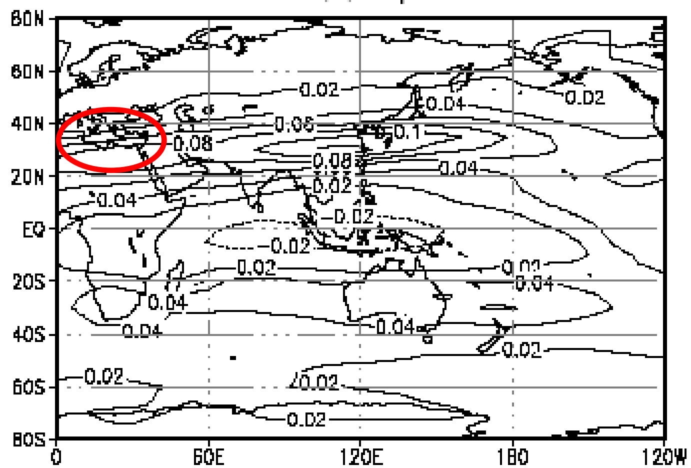
Pressure velocity

(a) $\tilde{\omega}$



Climatological vertical wind shear

(b) $\overline{U}_T$



Combining tilting & vertical advection

- The sum of vertical vorticity advection term and tilting term is expressed as:

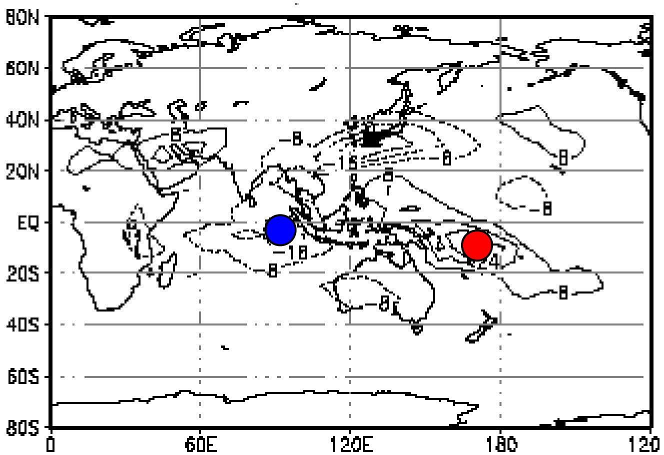
$$-\widehat{w}\frac{\partial\bar{\zeta}}{\partial z}+\mathbf{k}\cdot\left(\frac{\partial\bar{\mathbf{V}}_{\psi}}{\partial z}\times\nabla\widehat{w}\right)\simeq\widehat{w}\frac{\partial}{\partial z}\frac{\partial\bar{u}_{\psi}}{\partial y}+\frac{\partial\bar{u}_{\psi}}{\partial z}\frac{\partial\widehat{w}}{\partial y}$$

$$\widehat{w}\frac{\partial}{\partial z}\frac{\partial\bar{u}_{\psi}}{\partial y}+\frac{\partial\bar{u}_{\psi}}{\partial z}\frac{\partial\widehat{w}}{\partial y}\simeq-\widehat{w}\frac{\partial\bar{U}_{T}}{\partial y}-\frac{\partial\widehat{w}}{\partial y}\bar{U}_{T}=-\frac{\partial}{\partial y}\left(\widehat{w}\bar{U}_{T}\right)$$

where, $\bar{U}_{T}=\dfrac{\partial\bar{u}_{\psi}}{\partial z}$

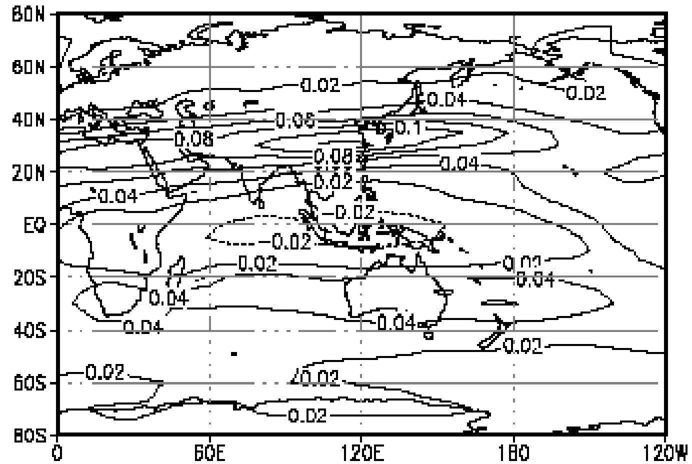
Combining tilting & vertical advection: Baroclinic Jet Source (BJS)

$\tilde{\omega}$ $\bigotimes$ $\bar{U}_T$

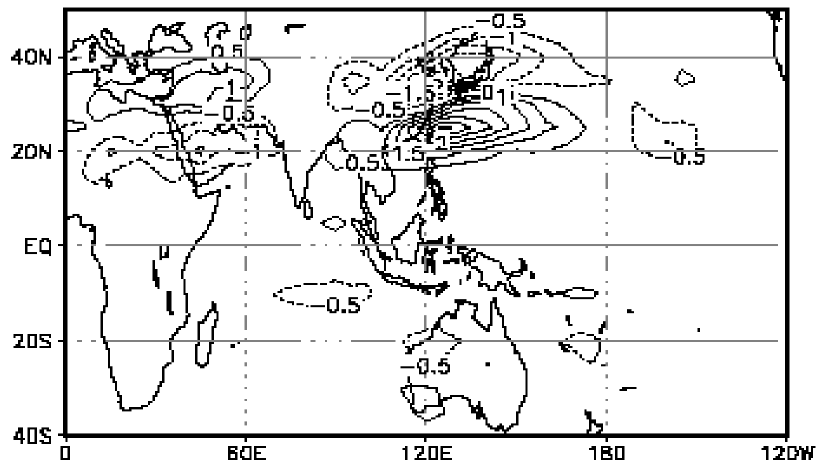


:Wet center :Dry center

$$-\frac{\partial}{\partial y}(\ \bullet\ )$$



BJS: $-\frac{\partial}{\partial y}(\tilde{\omega}\bar{U}_T)$



Barotropic model experiment

•To confirm that BJS gives important role in developing the midlatitude-MJO teleconnection, a linear barotropic model experiment is conducted.

•In this experiment, basic state is fixed to zonal mean structure.

•Model formula:

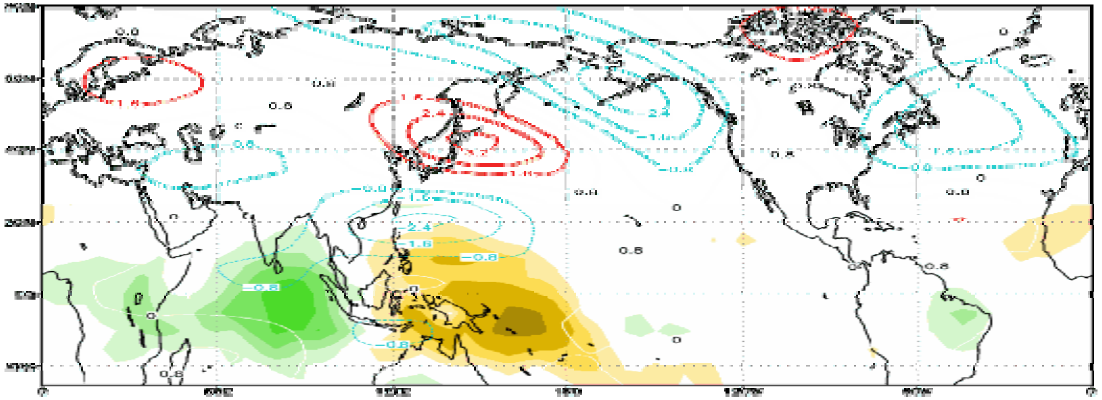
BJS

$$\frac{\partial}{\partial t}\nabla^2\psi' = -[\bar{\mathbf{V}}_\psi]\cdot\nabla\zeta' - \mathbf{V}'_\psi\cdot\nabla[\bar{\eta}] + F(t) - \epsilon\,\zeta - \nu\nabla^4\zeta'$$

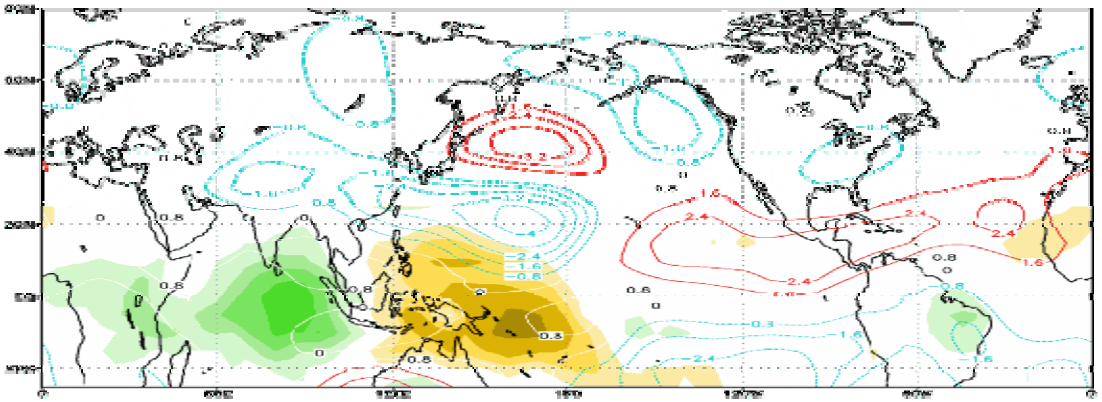
Symbol	Explanation
ψ'	perturbation stream function (dependent variable)
ζ'	perturbation vorticity(derived from ψ')
$\mathbf{V}'_\psi$	perturbation horizontal wind(derived from ψ')
$[\bar{\mathbf{V}}_\psi]$	zonal mean winter time climatological horizontal wind(basic state)
$[\bar{\eta}]$	zonal mean winter time climatological absolute vorticity(basic state)
$F(t)$	periodic forcing term (45day period, 45×3 days length)
ϵ	rayleigh friction coefficient(10.7day^{-1})
ν	biharmonic diffusion coefficient ($2.338\times10^{16}m^2s^{-1}$)

Barotropic model experiment

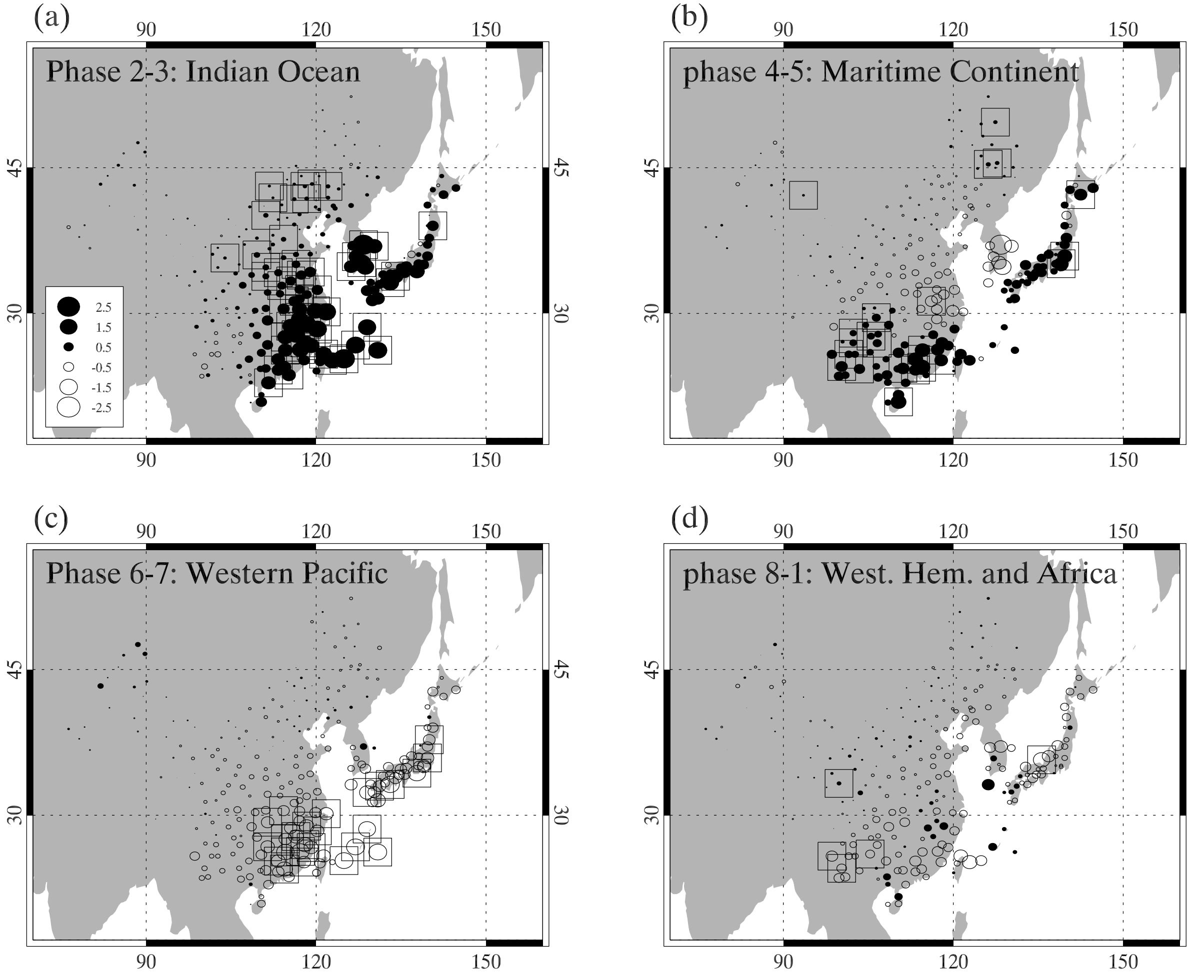
Model streamfunction forced by BJS



Regressed cycle of 300mb streamfunction



Precipitation over East Asia modulated by MJO-Teleconnection

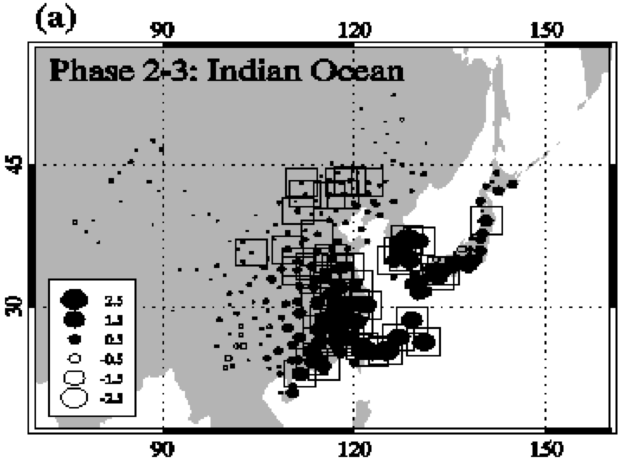


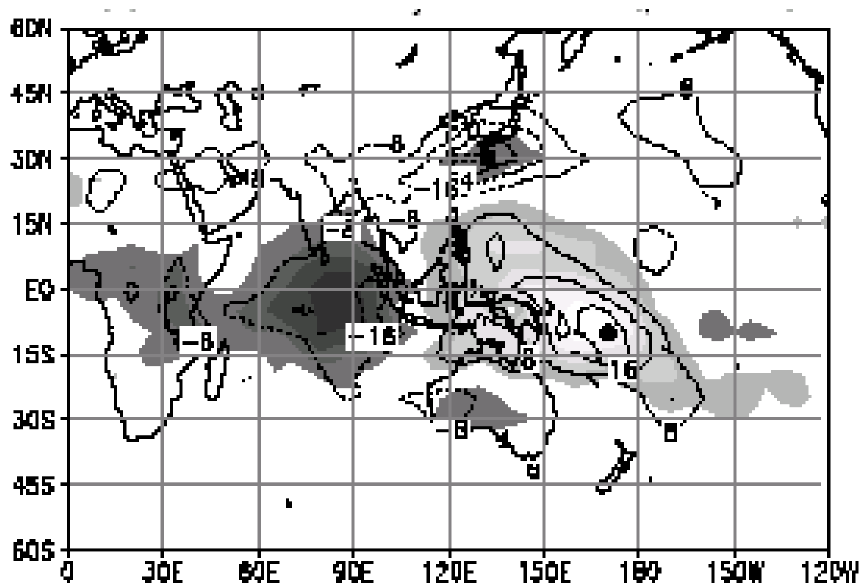
- Composite precipitation rate anomaly (mm day^{-1}) in each of categorized MJO phases

- Composite values significant at the 99% confidence level are marked by square.

•The winter precipitation over East Asian coast is strongly modulated by MJO if we note the mean of most of station is near 4mm/day.

•This is related with the vertical motion induced by the dynamic balance between MJO and Winter East-Asian Jet.





Summary

•In principle, broad feature of MJO-teleconnection can be understood as forced linear response over non-zonal basic state.

•The East Asian Jet and Rossby gyres produced by MJO convection anomalies interact.

•This interaction needs vertical motion near the jet center region to maintain dynamic (mostly QG) balance.

•The tilting and vertical advection terms are largely enhanced due to the vertical motion near the jet-core region.

•These can be combined and defined as Baroclinic Jet Source (BJS).

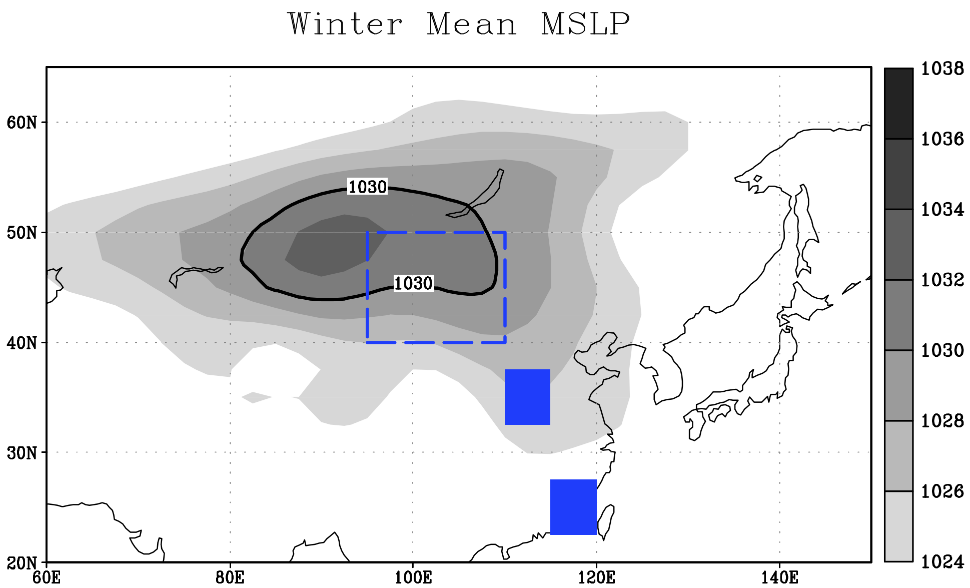
•Due to the dipolar structure of BJS, the teleconnection pattern becomes zonally elongated north/south dipole.

•We have quantitatively shown that surface temperature , cold surge event and winter precipitation over East Asian coast are modulated by MJO-teleconnection.

MJO is no more just tropical phenomena!

Thank you

Cold surge criteria used in this study



① Surface anticyclone over southern Siberia [*Zhang and Wang*, 1997]

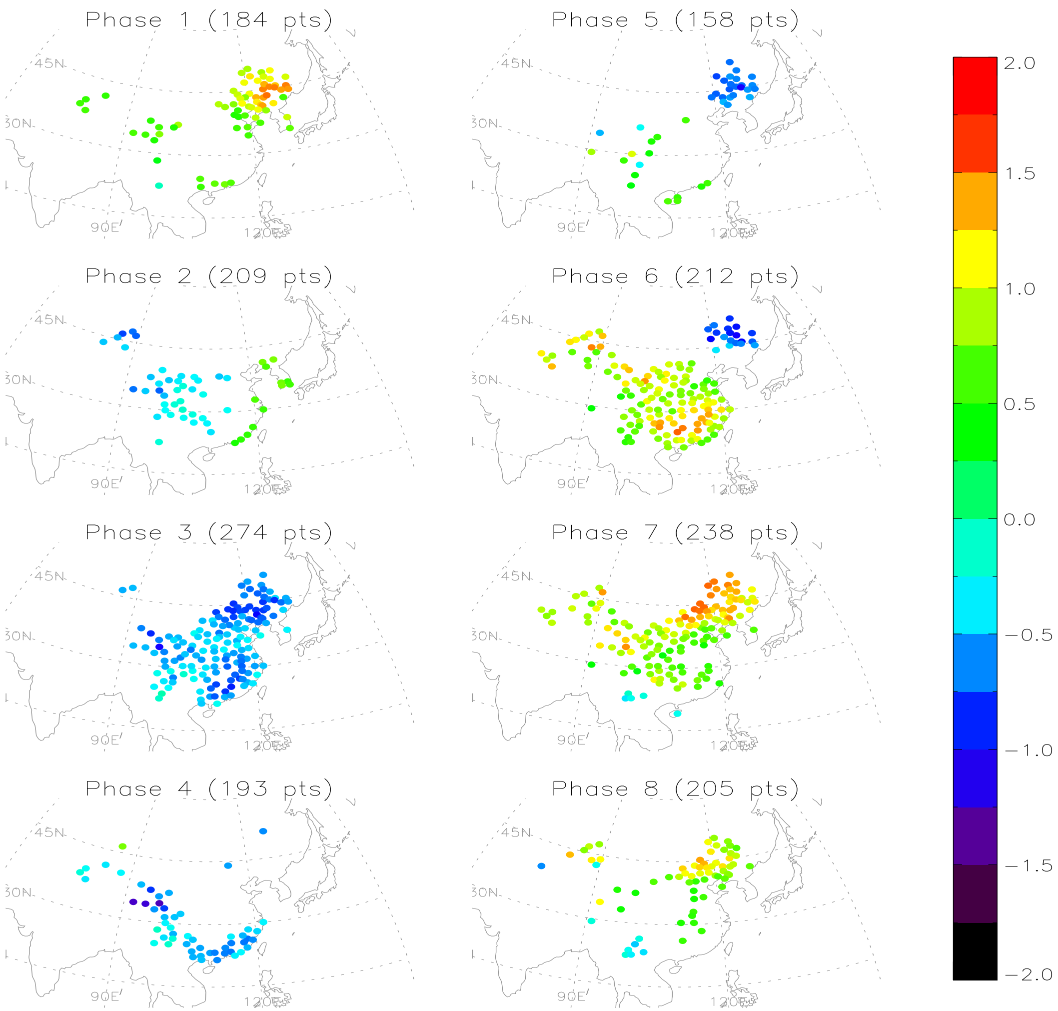
- Local Maximum of Z
- Negative vorticity
- Minimum SLP -1035 hPa

② Decreased SAT value within two days exceeds 1.5σ

③ Strong northerly wind speed (≥1.5 σ) in mid China

During 43 winters, 357 cold surges have been identified in total, i.e. 8.3 per year.

Composite SAT based on 8 MJO phases

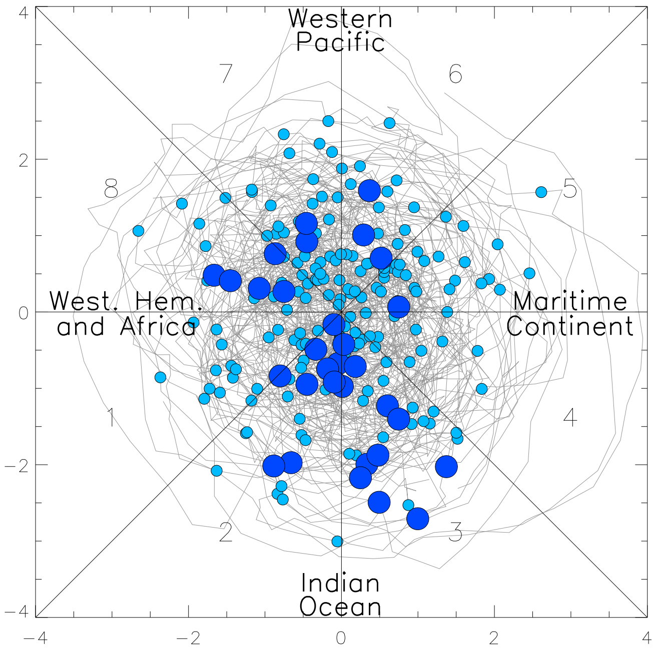


Composite anomaly statistically significant over 90% are chosen.

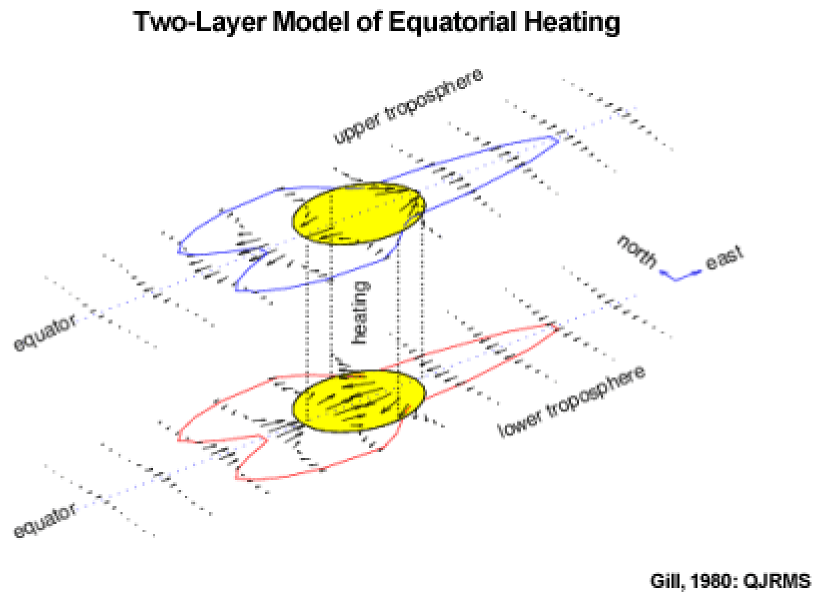
Cold surge statistics for 27 winters

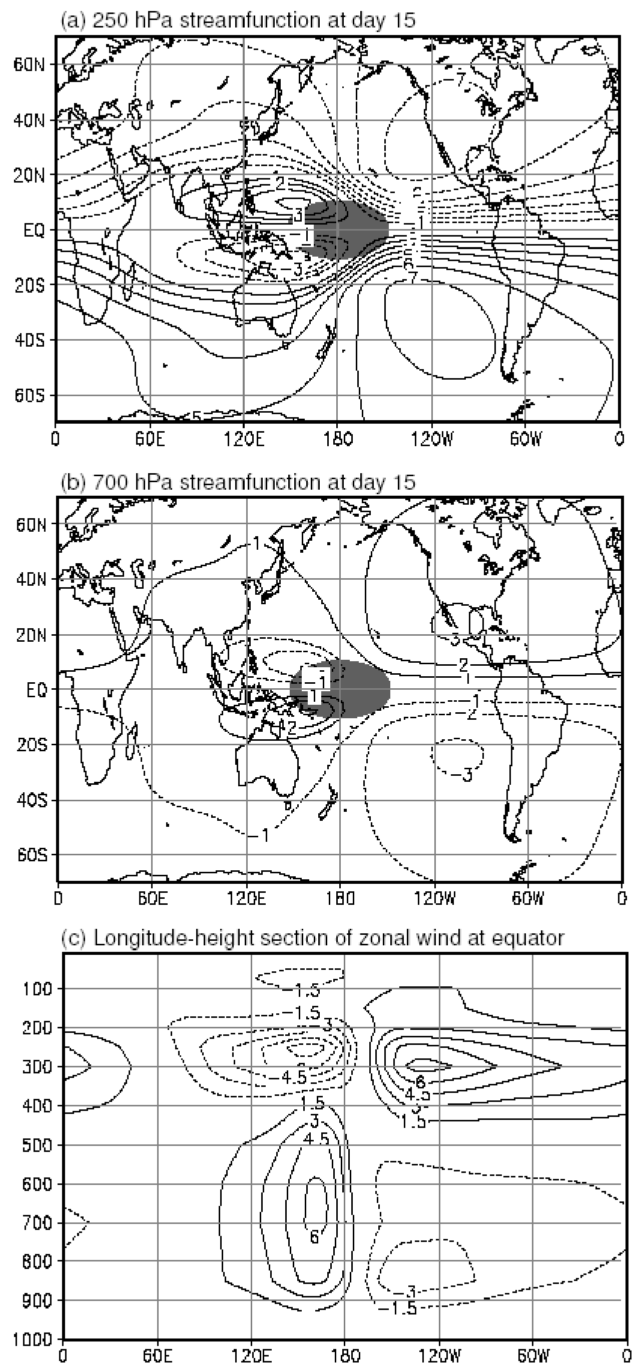
- Identified occurrences of cold surges overlapping on the phase-space diagram of MJO (RMM1, RMM2).

- Small and large circles denote all and extreme cold surges respectively.



Exp 1, Gill-Matsuno Problem,Single,Rest





Regression

•NCEP/NCAR daily reanalysis2 (00 UTC) , AVHRR OLR from NOAA polar orbiting satellites are used.

•Twenty-one consecutive winters (November through the following March) from 1979/1980~1999/2000 were analyzed.

•Annual cycle has been removed before analysis.

•30-100 filtered EOF1 & EOF2 PC time series are used to define MJO phases.

•Following *Mathews* [2000], variables are regressed on the PC time series.

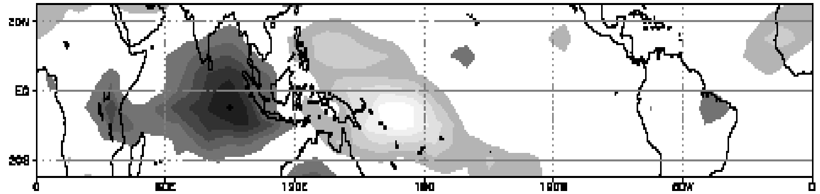
$$\widehat{OLR}(\alpha) = 6 \cdot \mathrm{EOF1} \cdot \cos\alpha + 6 \cdot \mathrm{EOF2} \cdot \sin\alpha$$

$$\hat{y}_i(\alpha) = \hat{y}_{1i} \cdot \cos\alpha + \hat{y}_{2i} \cdot \sin\alpha \ ,$$

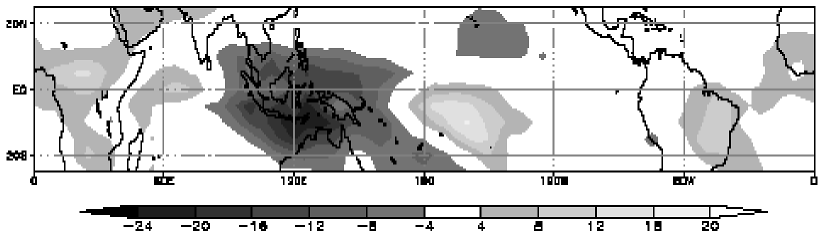
$$\widehat{y}_{1i} = a_{1i} + b_{1i} \cdot \mathrm{PC1}$$

$$\widehat{y}_{2i} = a_{2i} + b_{2i} \cdot \mathrm{PC2}$$

•EOF1

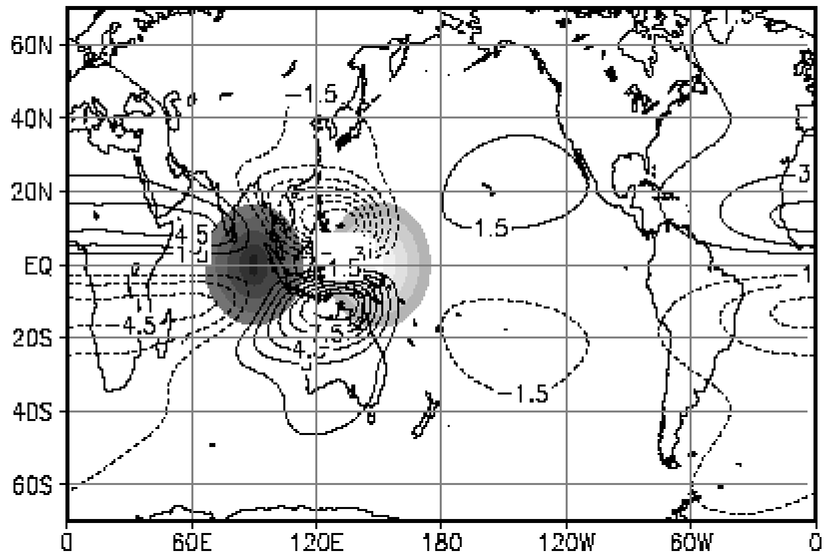


•EOF2

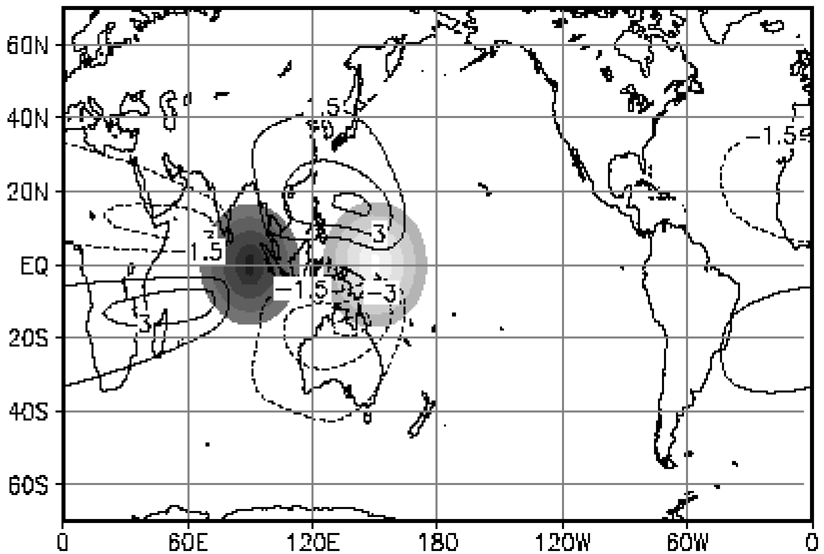


Exp 2, Dipole, Rest

(a) 250 hPa streamfunction at day 15

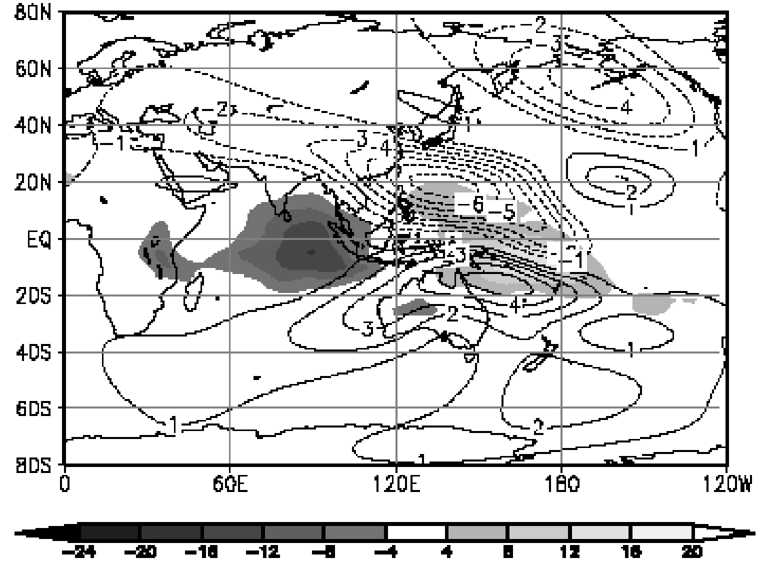


(b) 700 hPa streamfunction at day 15

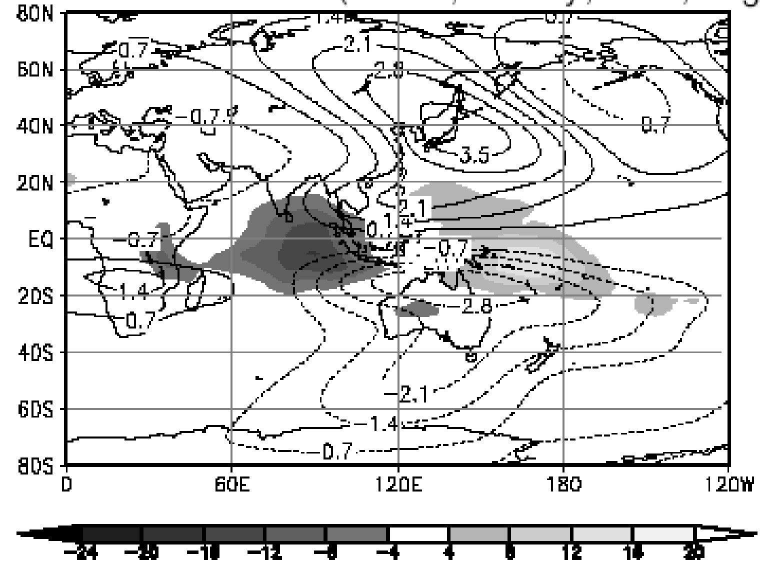


Exp 3, OLR, Zonal

300 hPa streamfunction (LinZm, Steady, MJO, angle= 0)



700 hPa streamfunction (LinZm, Steady, MJO, angle= 0)



Partitioning

•The GOE is solved by applying SOR method to equation forced by each partitioned forcing term sequentially.

•The real benefit comes from GOE is partitioning of omega ascribed to different cause (forcing)'

$$\omega_1 = \quad {L_1}^{-1} F_{QG}$$: Omega from balanced dynamics

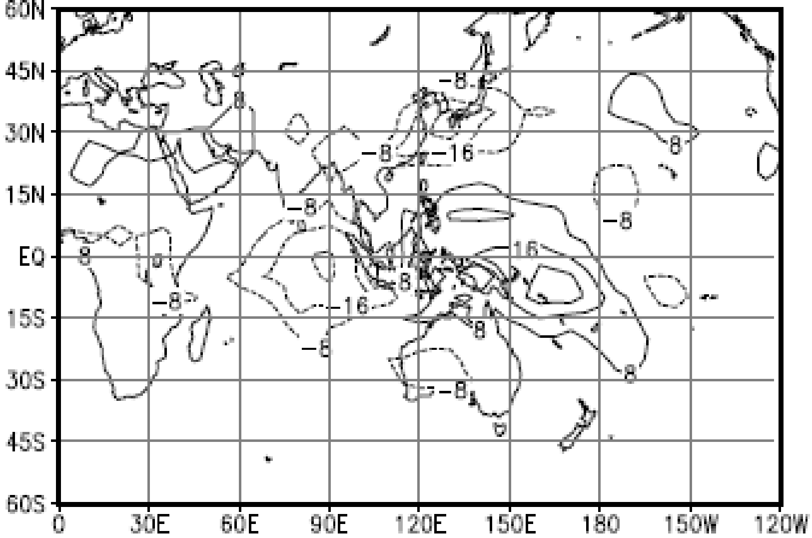
$$\underbrace{\omega_1 = \quad {L_1}^{-1}}_{\omega_{11} \quad \omega_{12} \quad \omega_{13} \quad \omega_{14}}$$

$$\omega_2 = \quad {L_1}^{-1} F_H$$: Omega from balancing thermodynaics

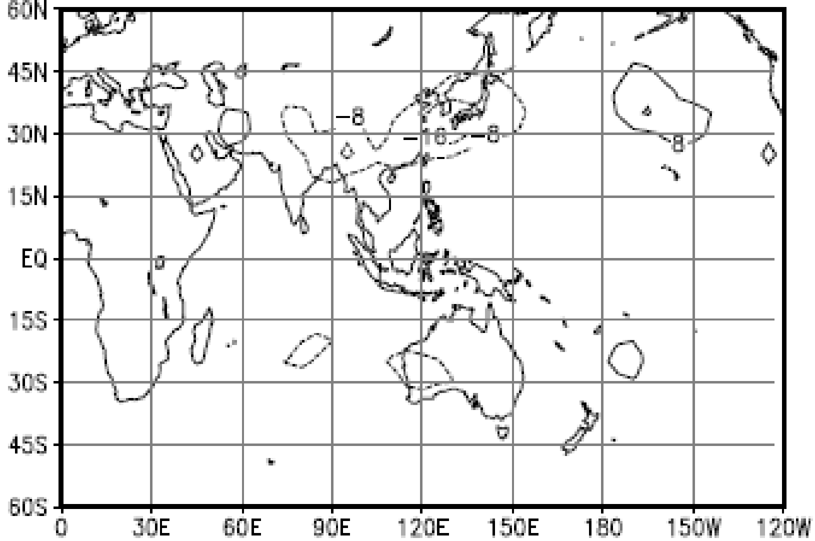
$$\omega_3 = - {L_1}^{-1} L_2 \omega^*$$: Omega due to non-geostrophic processes

$$\omega^* = \quad \omega_1 + \omega_2 + \omega_3$$

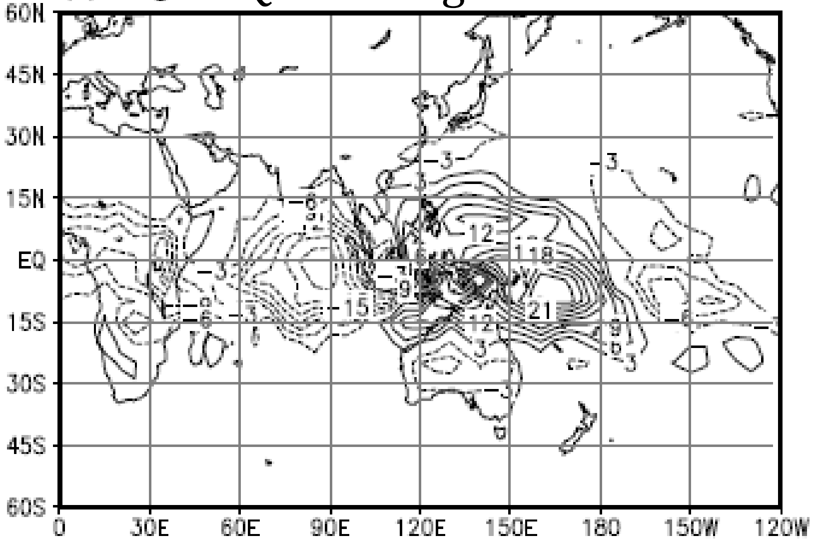
•ω from all forcings



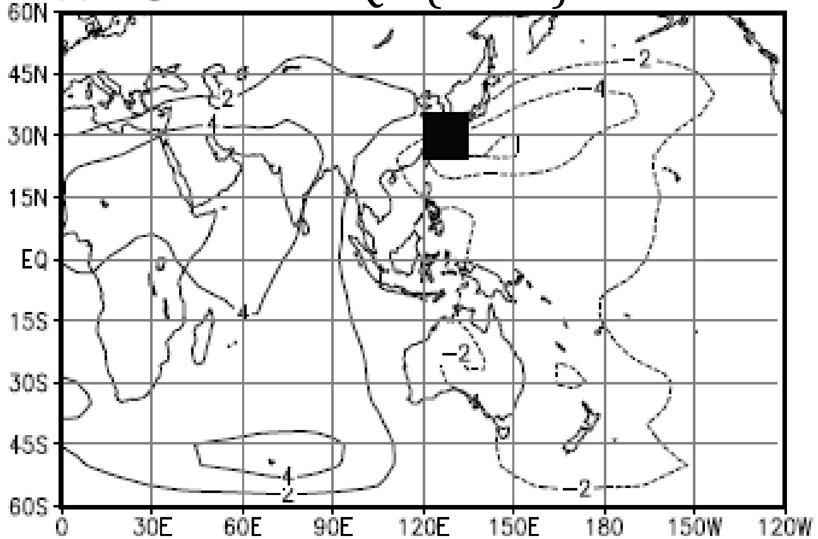
•ω from QG forcing



•ω from QG heating



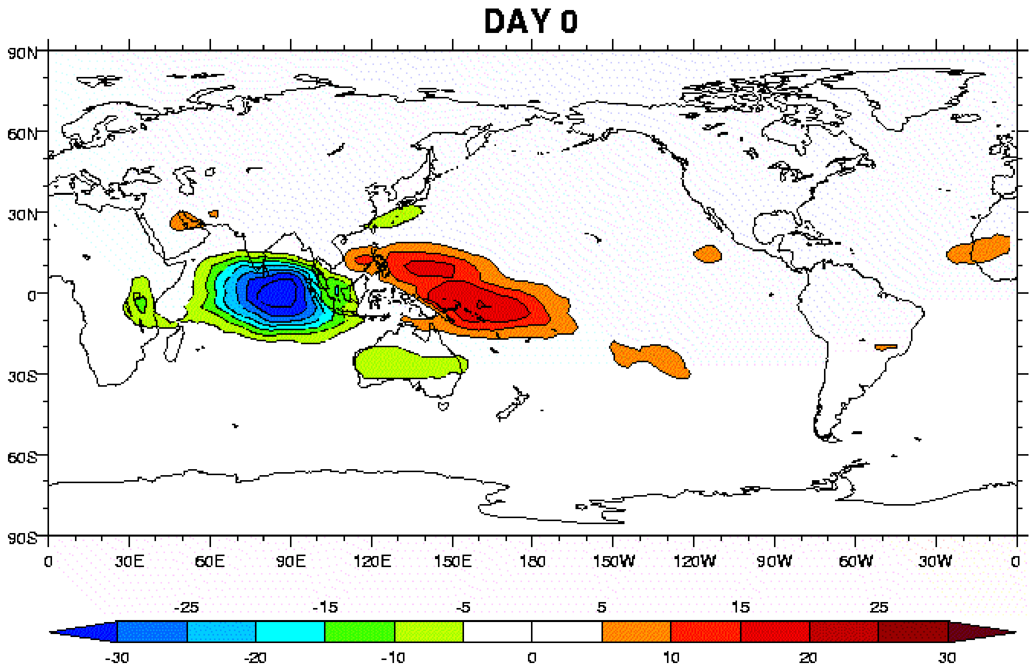
•ω from non-QG (small)

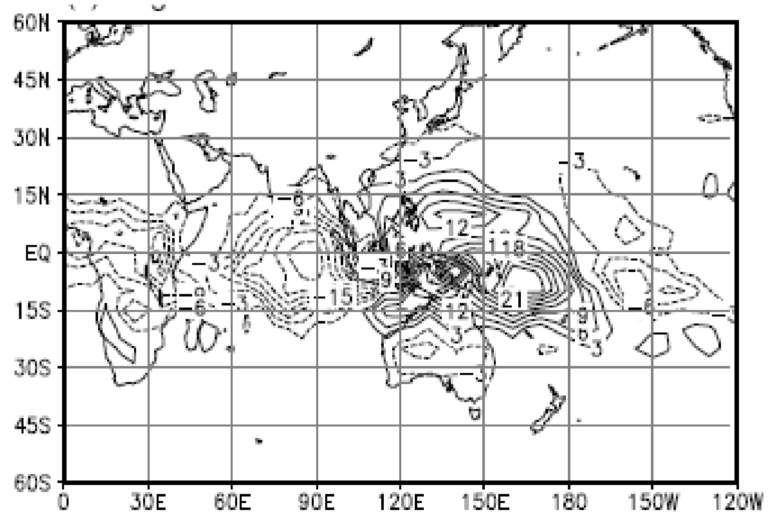


Vertical motion from heating

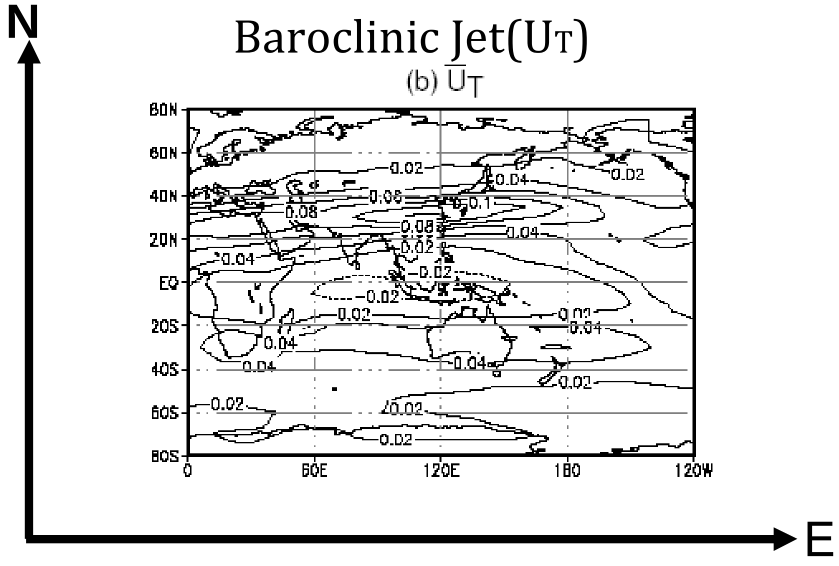
•From the analysis of omega equation, we can safely insist that some subtropical OLR anomaly has dynamic (QG) origin.

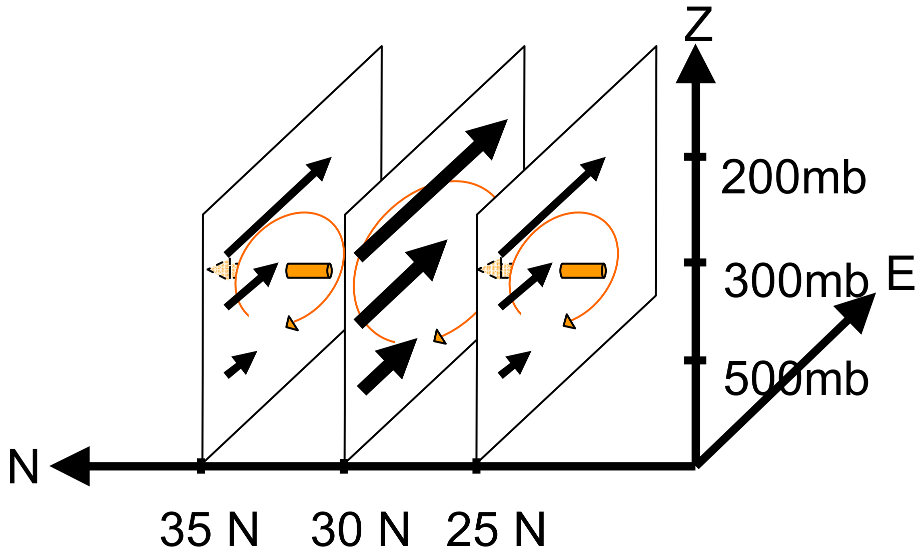
•i.e. Dynamic response -> Vertical motion -> Convection

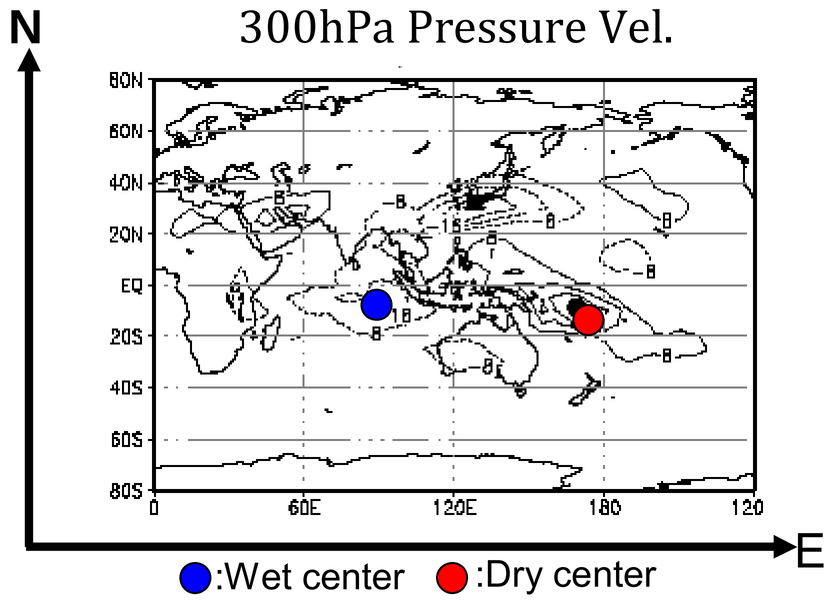


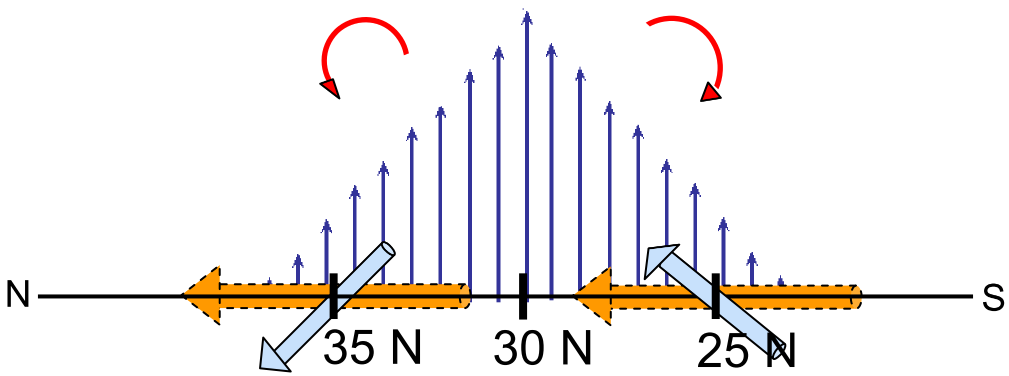


How tilting can give dipolar vortex source?

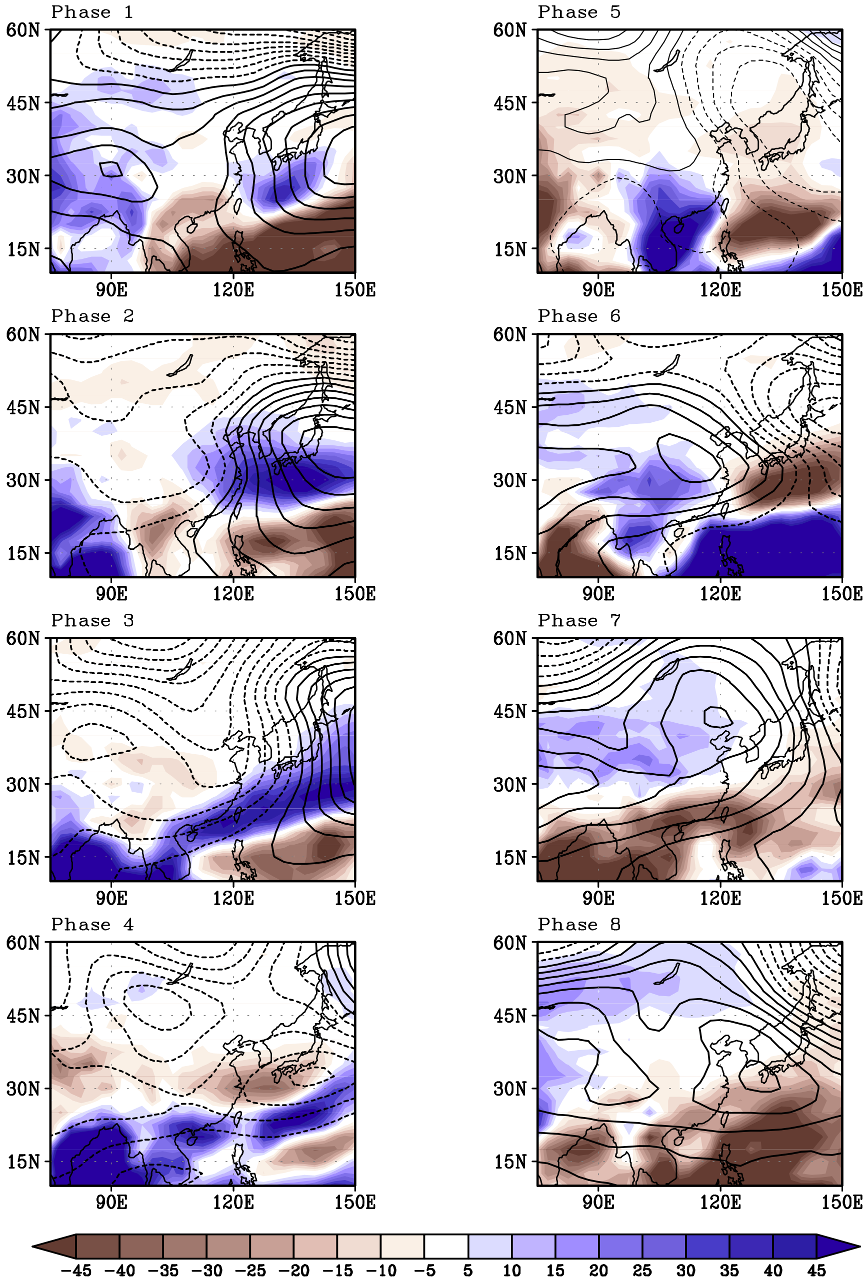








Composite SAT based on 8 MJO phases



- Composite geopotential height (contour; 4 m interval) and specific humidity (shaded; 10-5 kg/kg) anomaly at 700 hPa with respect to eight MJO phases in wintertime.

- Trough intrusion(phase 3) and High anomaly (phase 7) are consistent with SAT anomaly.

- Dry (Phase 3) and humid(Phase 7) conditions may influence cold surge event.