

Cause of Seasonality of Intraseasonal Oscillations in the Tropical Atmosphere and Ocean

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Acknowledgement: Xianan Jiang, Francis Tam, Chunhua Zhou

Outline:

- ISO seasonality in the atmosphere – A thermal equator hypothesis
- Seasonal dependence of intraseasonal SST variability – A background wind-thermocline dome control hypothesis

Introduction

➤ **ISO, first detected by Madden and Julian (1971, 1972), is one of the most significant signals in the tropical atmosphere.**

Major features of MJO: eastward propagation, period: 30-60 days, length scale: zonal wavenumber 1 or 2

➤ **ISO is season and geographic location dependent: Northward propagation in summer Indian Ocean, westward propagation off the equator in the WNP (e.g., Yasunari 1979, Wang and Rui 1990)**

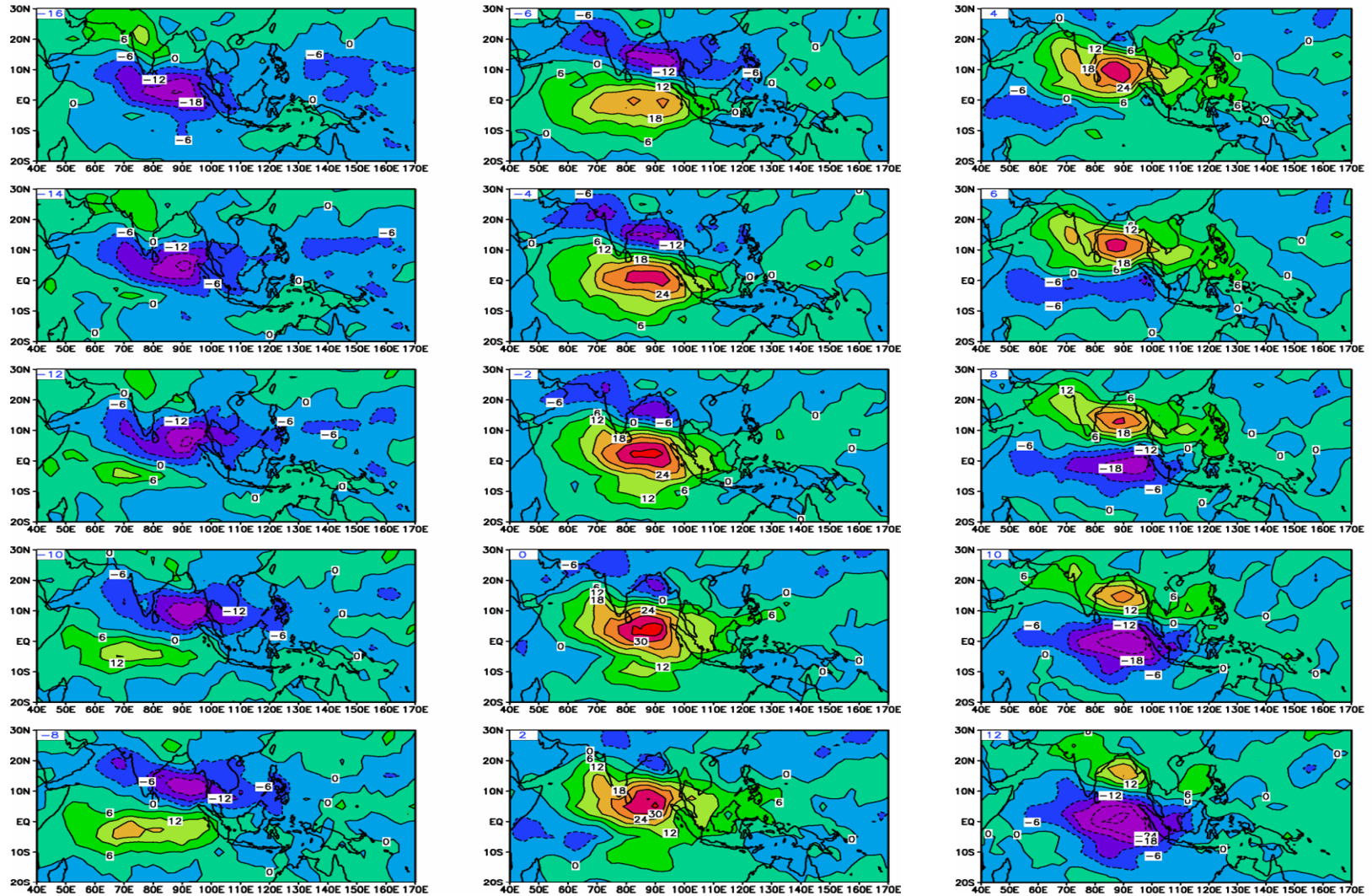
➤ **SST also exhibits significant intraseasonal variability.**

Scientific questions to be addressed:

• **What cause the seasonal variability of intraseasonal oscillations in the tropical atmosphere and ocean?**

1. Seasonality of the ISO in the Tropical Atmosphere

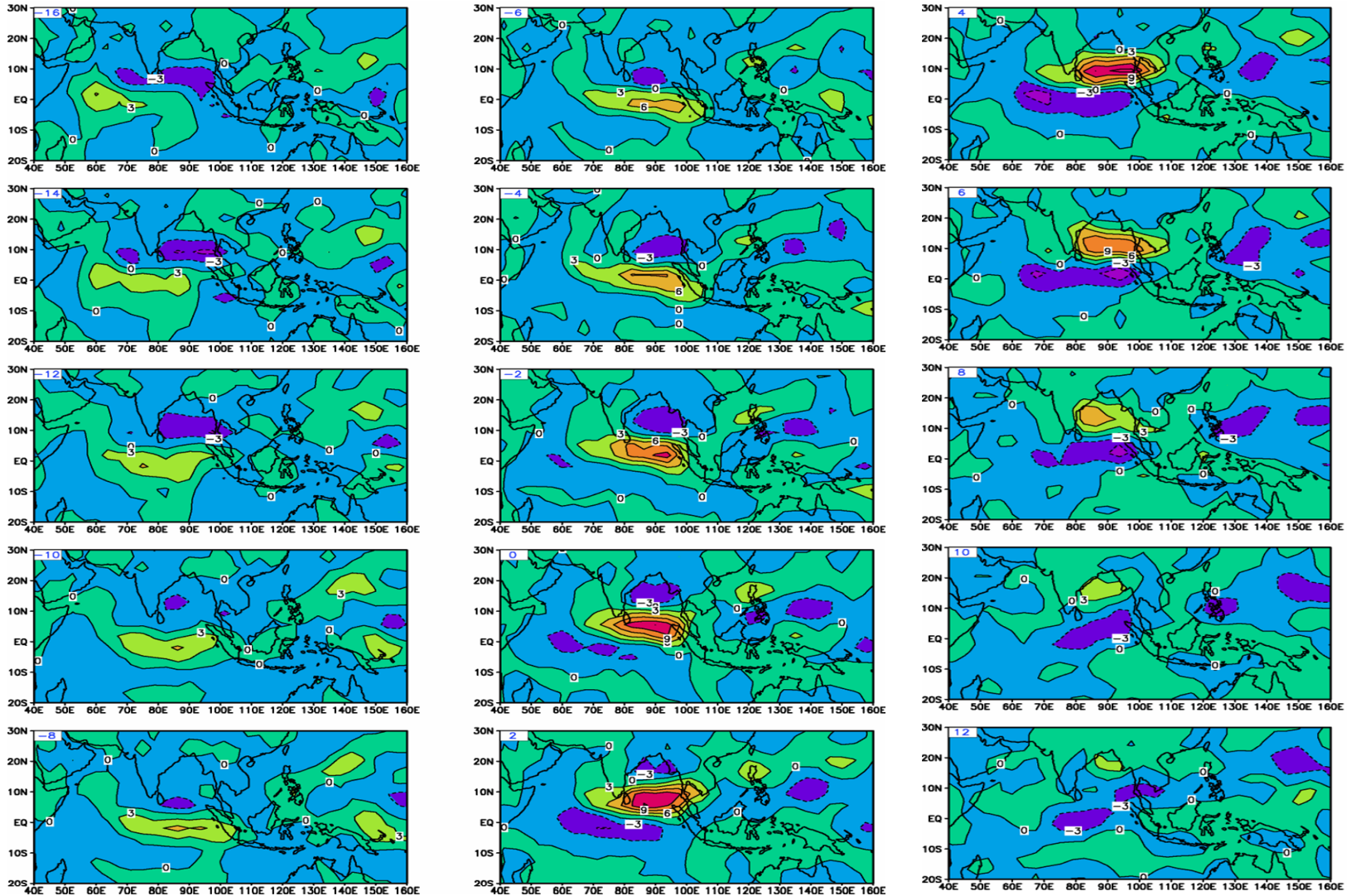
Observed OLR Composite in northern summer



Winter: continuous eastward propagation across the maritime continent

Summer: northward bifurcation over the eastern IO/maritime continent

ECHAM4 Simulation



What is the effect of the maritime continent? 1) friction, 2) moisture reduction, 3) diurnal cycle

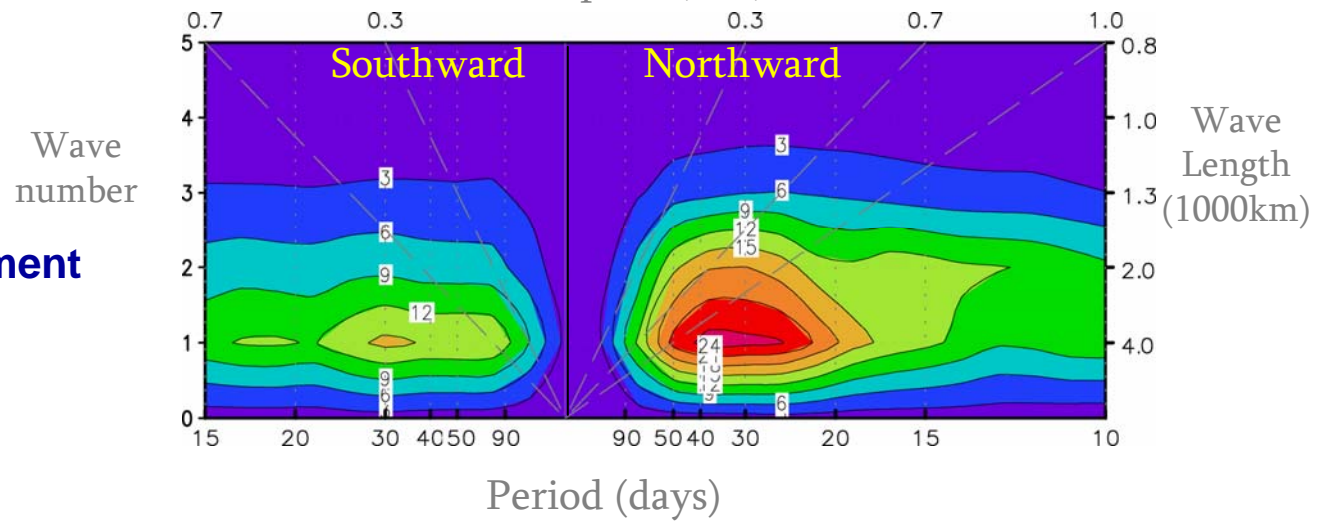
Idealized numerical experiments: removing the maritime continent with interpolated SSTs from the surrounding ocean

Frequency – wavenumber analysis

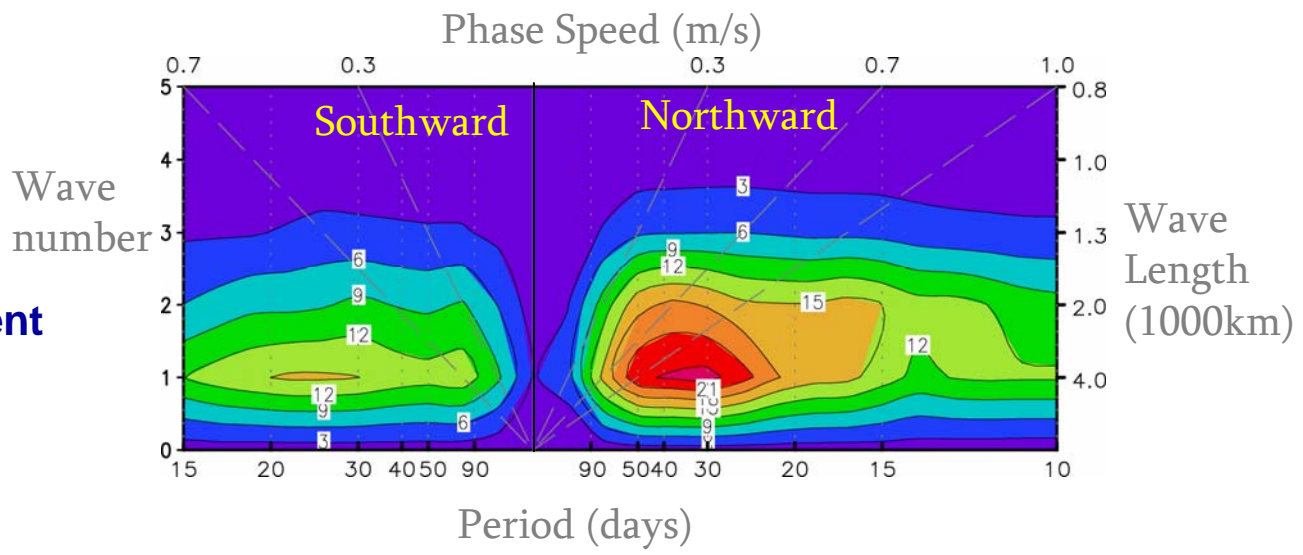
(75-95°E)

Phase Speed (m/s)

Control Experiment



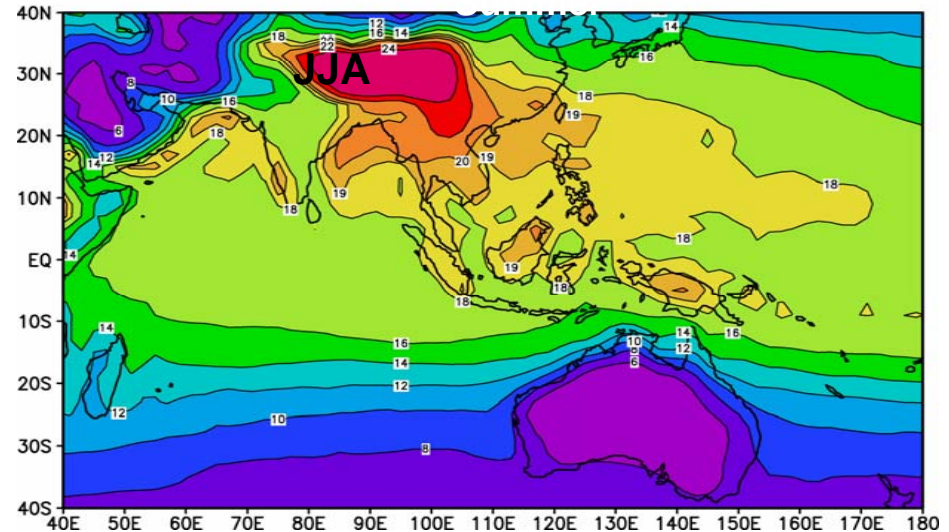
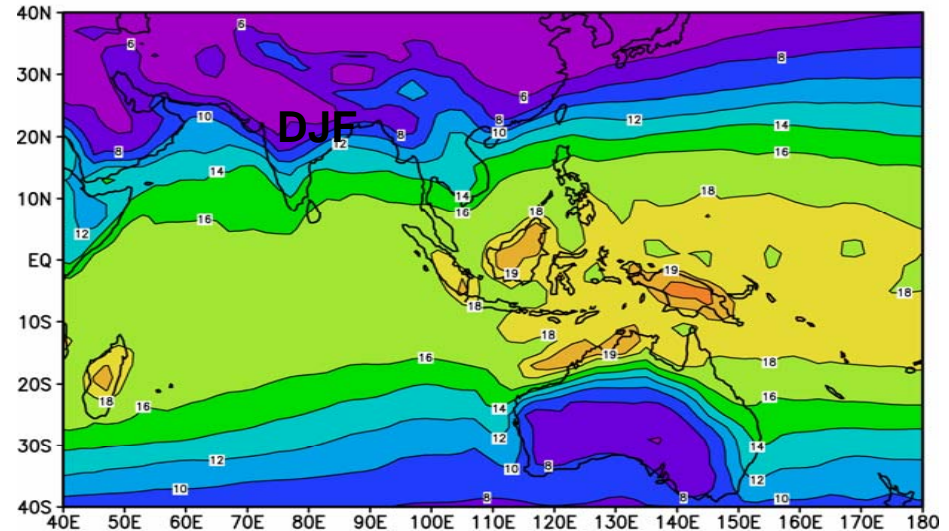
No-MC experiment



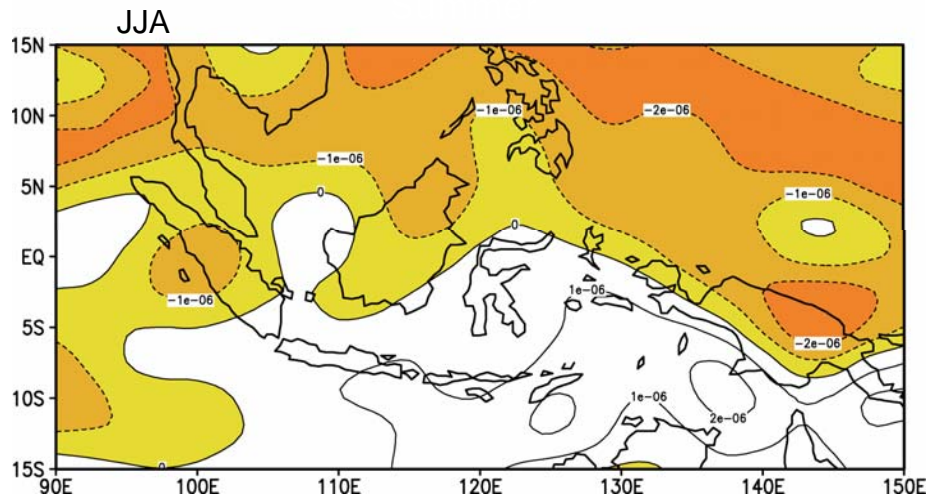
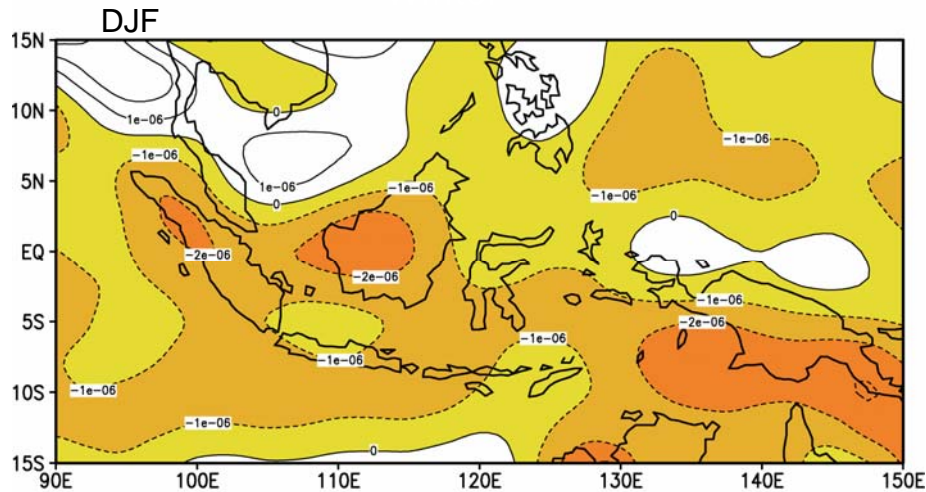
Moisture at 1000 hPa

Hypothesis:

Atmospheric ISO seasonality is primarily caused by the asymmetry of a thermal equator between boreal summer and winter.



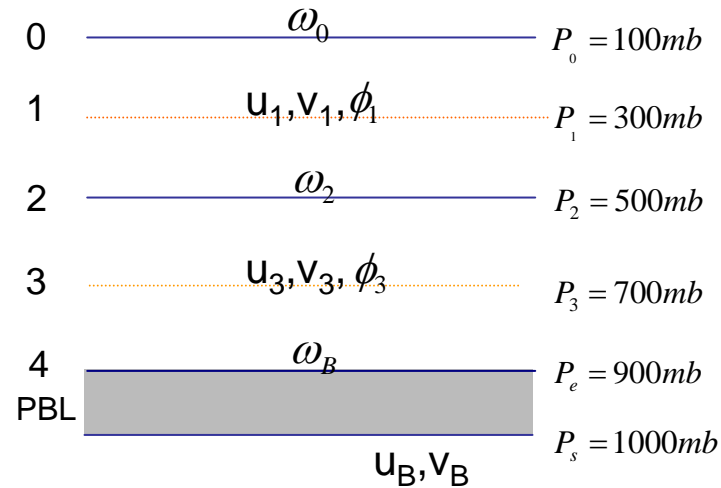
PBL divergence (1000-850mb)



Hypothesis(cont'd):

- **boreal winter:** Atmospheric moist Kelvin waves are unstable while Rossby waves are stable → Maximum perturbation is confined near the equator and ISO moves eastward
- **boreal summer:** Atmospheric Kelvin Waves stabilize due to low-level divergence over MC → ISO Wave packet decoupled, and Rossby waves emanated from the wave packet.

A 2^{1/2} layer dynamic framework (Wang and Li 1993, 1994)



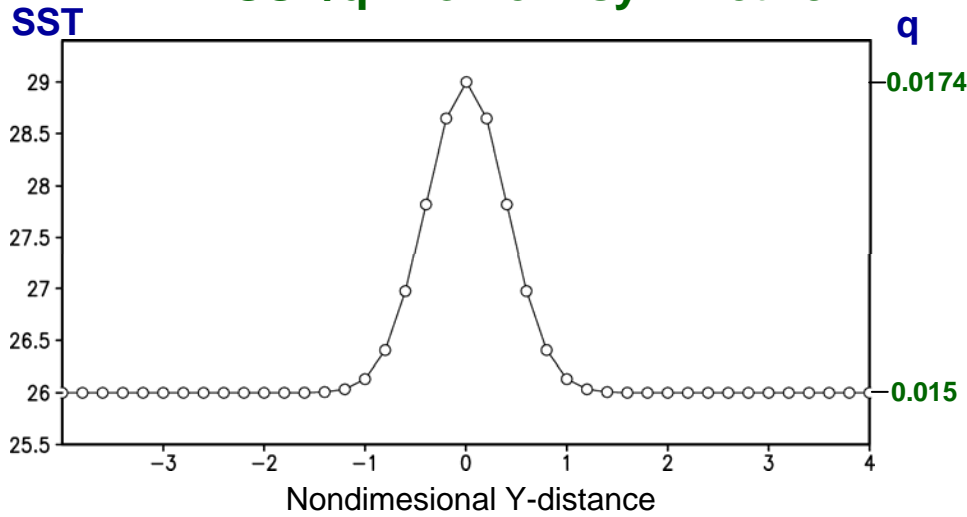
Nonlinear convective heating is proportional to moisture convergence at PBL:

$$Q \propto \delta \cdot B(q_e) \cdot \nabla \vec{V}_B$$

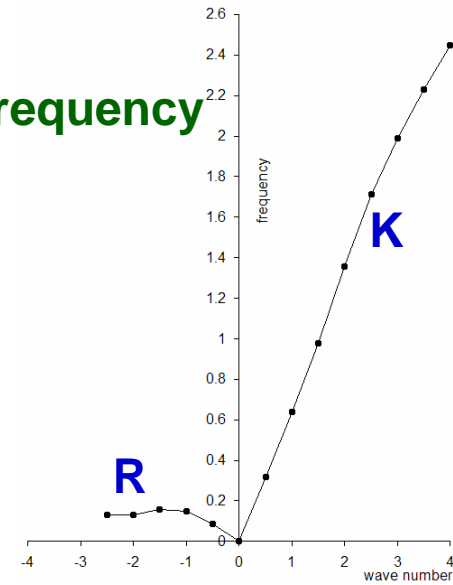
$\delta = 1, SST \geq 27^\circ C$ **and background low-level convergence**

$\delta = 0, SST < 27^\circ C$ **or background low-level divergence**

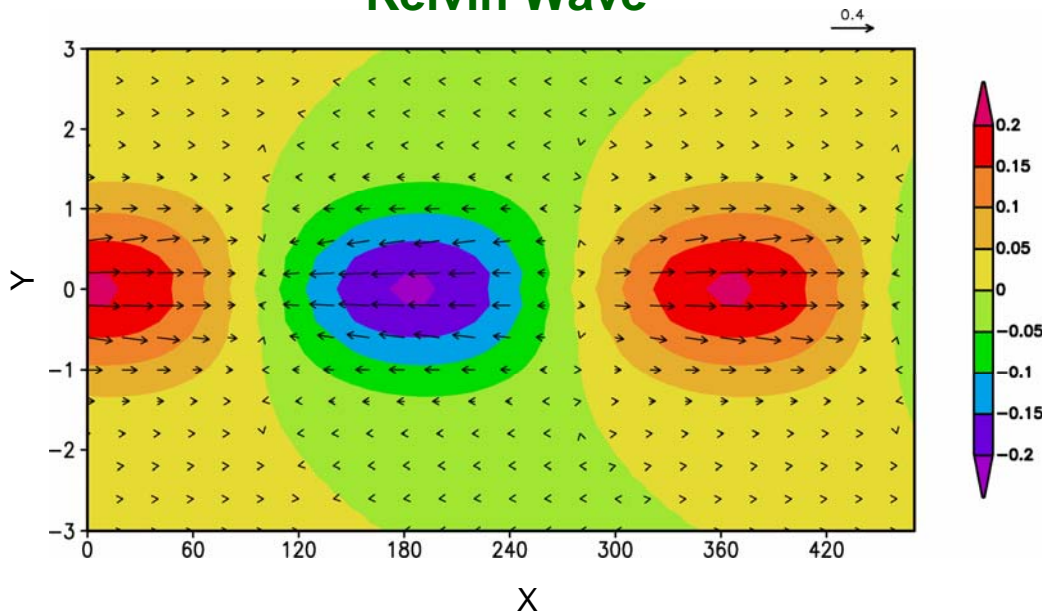
SST/q Profile -- symmetric



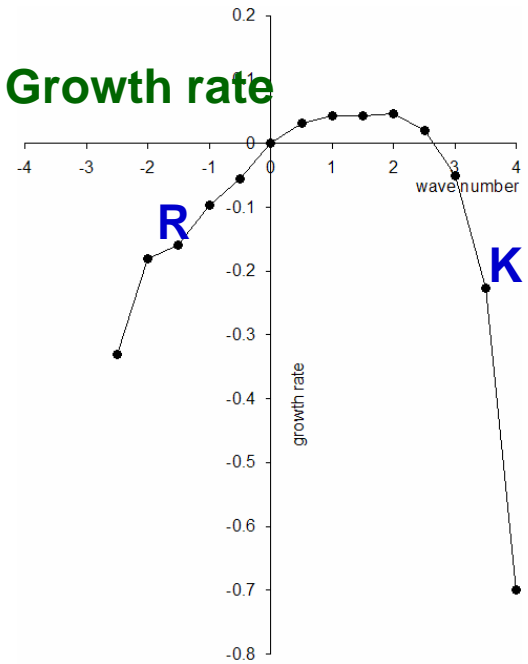
frequency



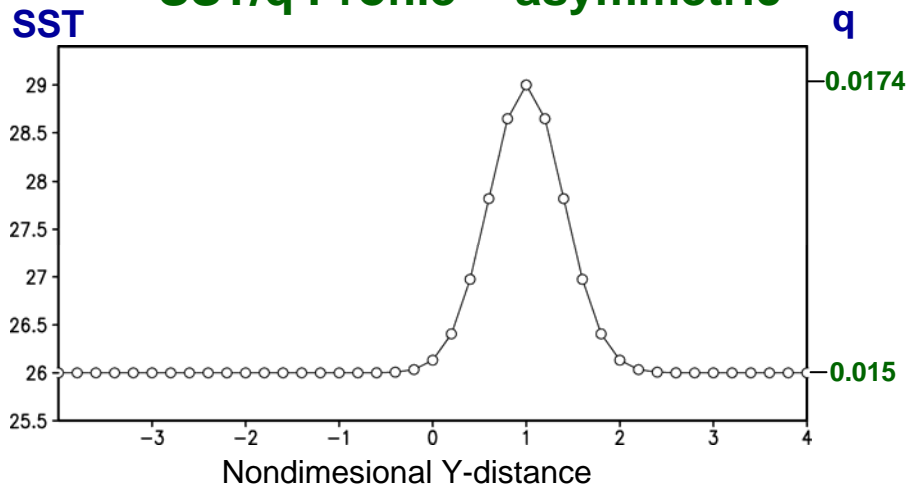
Kelvin Wave



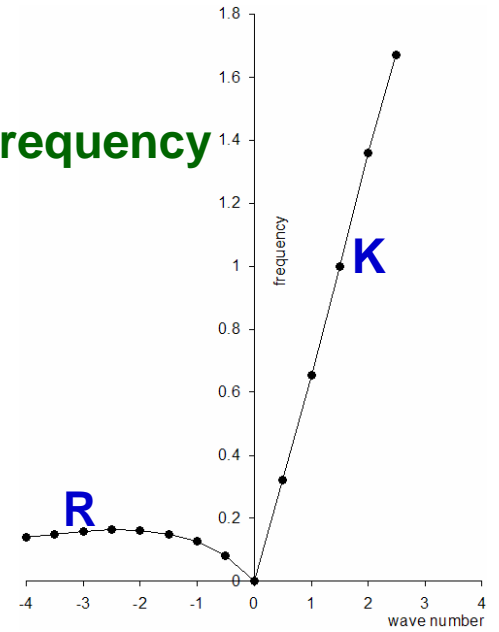
Growth rate



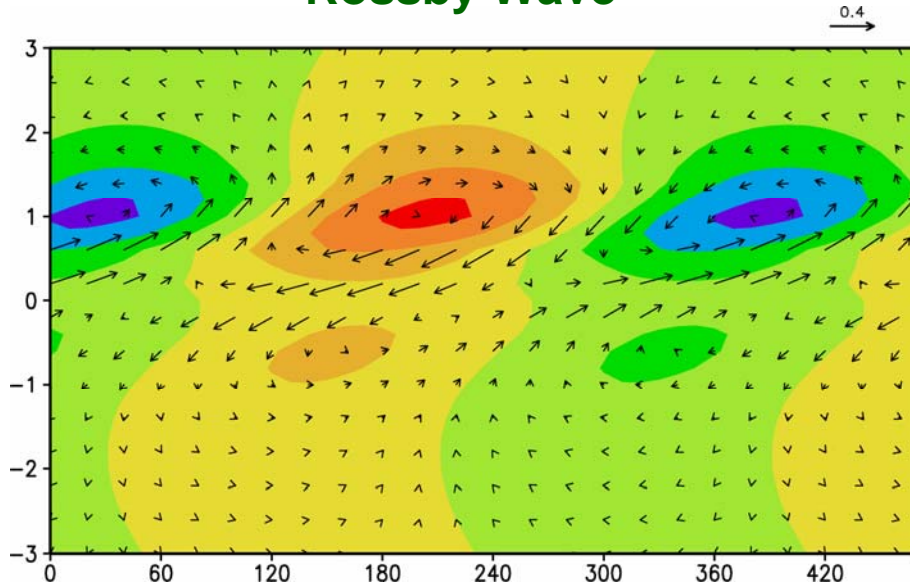
SST/q Profile -- asymmetric



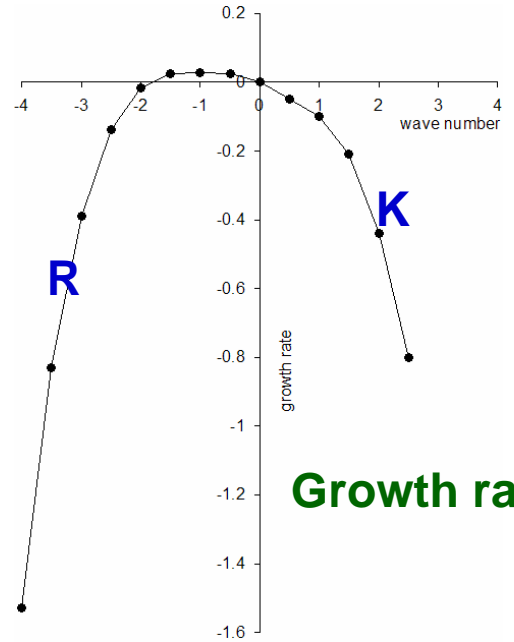
frequency



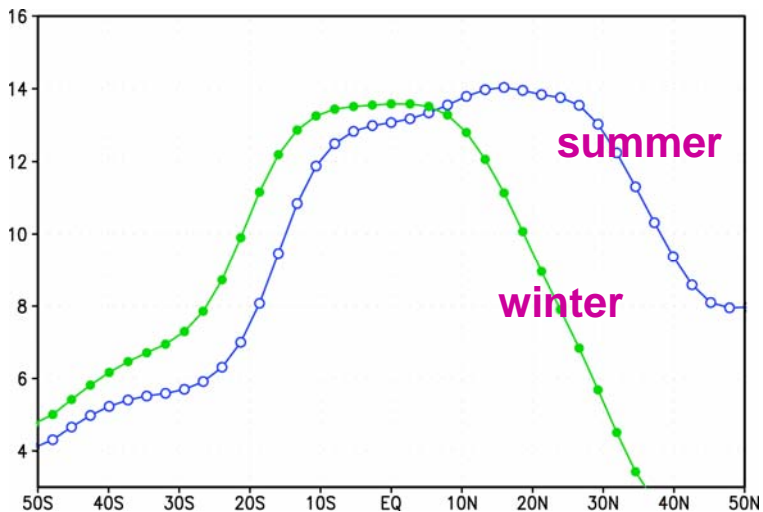
Rossby Wave



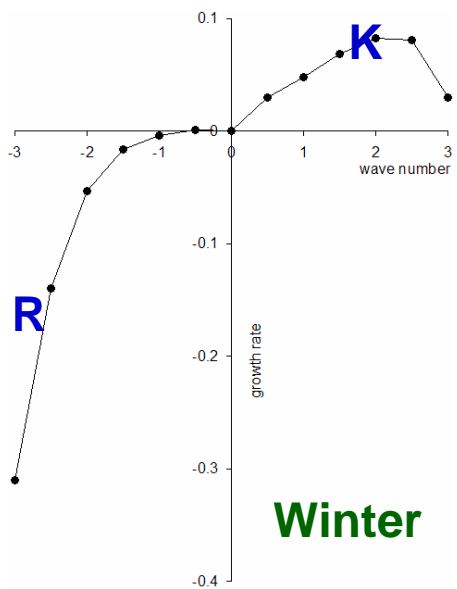
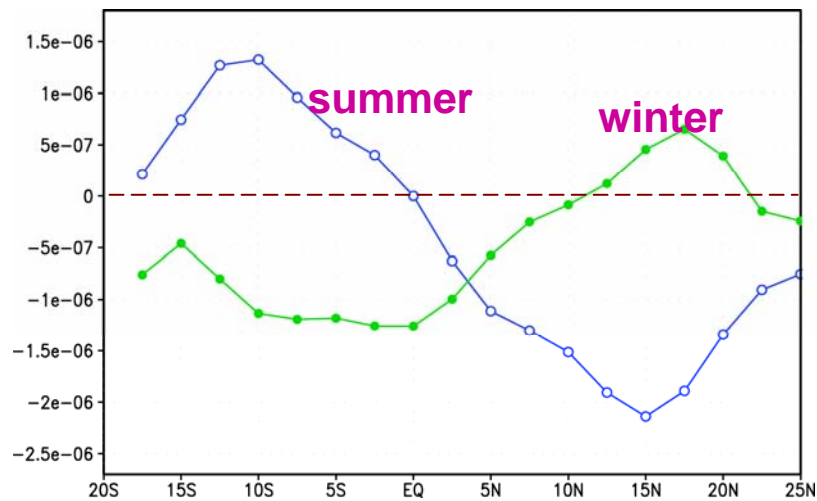
Growth rate



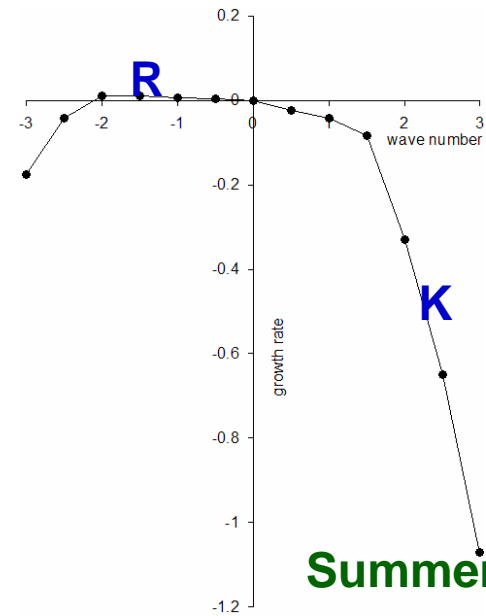
Specific humidity (900mb)



PBL divergence (110-140°E)



Growth rate

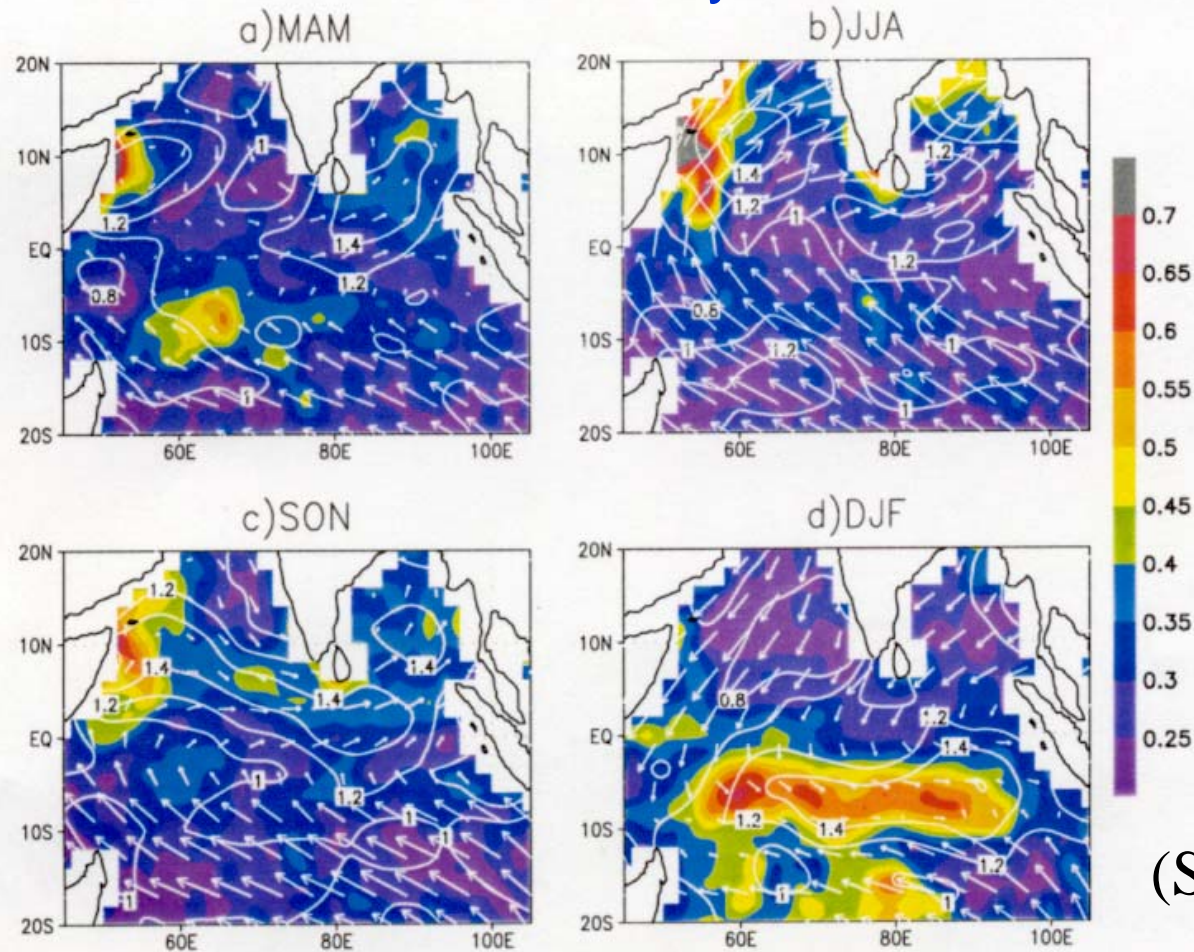


Summary 1: Seasonality of atmospheric ISO

- ✚ The maritime continent is not an essential factor that causes the winter-summer asymmetry in the ISO behavior.
- ✚ An eigenvalue analysis indicates that the equatorial asymmetry of the summer mean state over the maritime continent region leads to the decay of equatorial Kelvin waves but the growth of Rossby waves, whereas the winter mean state favors the growth of the Kelvin waves.
- ✚ The significant northward shift of the thermal equator in boreal summer is an essential cause of meridional bifurcation of the ISO over the eastern equatorial IO (off Sumatra).

2. Seasonality of the Intraseasonal SST Variability in the Tropical IO

Intraseasonal SST Variability over the Indian Ocean



(Saji et al. 2005)

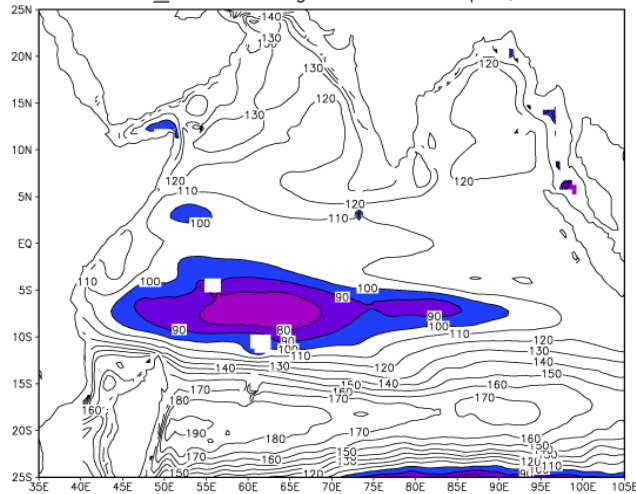
Figure 4: Standard deviation of SST ($^{\circ}\text{C}$; shaded) and wind speed (m/s; contour) on intraseasonal timescales during a) MAM, b) JJA, c) SON and d) DJF. Arrows in each panel indicate the climatological surface wind during the appropriate season.

Q: What determine the summer-winter asymmetry in the intraseasonal SST variability?

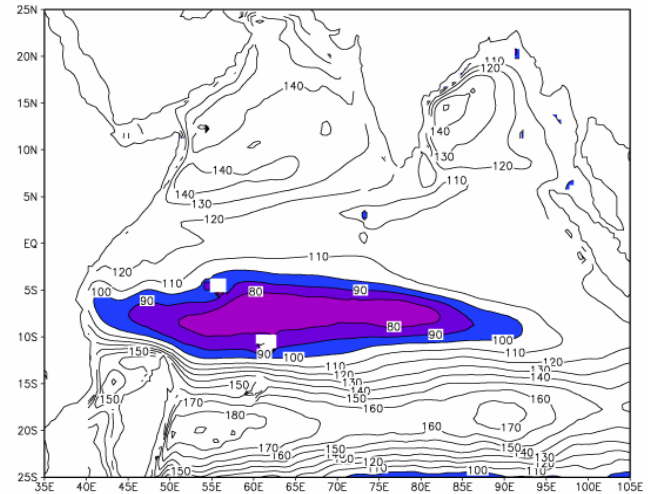
Q1: Why does the strong SST variability appear south of the equator?

An annual mean thermocline dome in the southern Indian Ocean

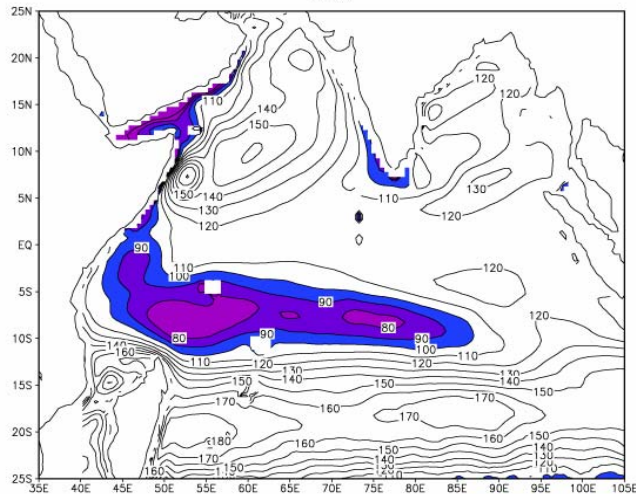
SODA_POP 20deg isotherm depth; DJF



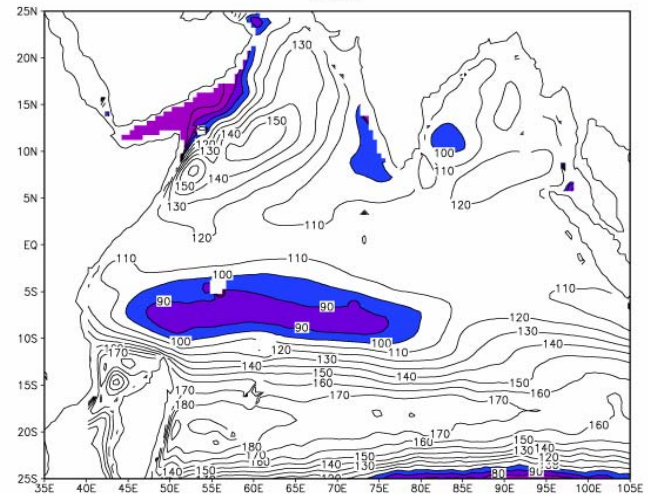
MAM



JJA



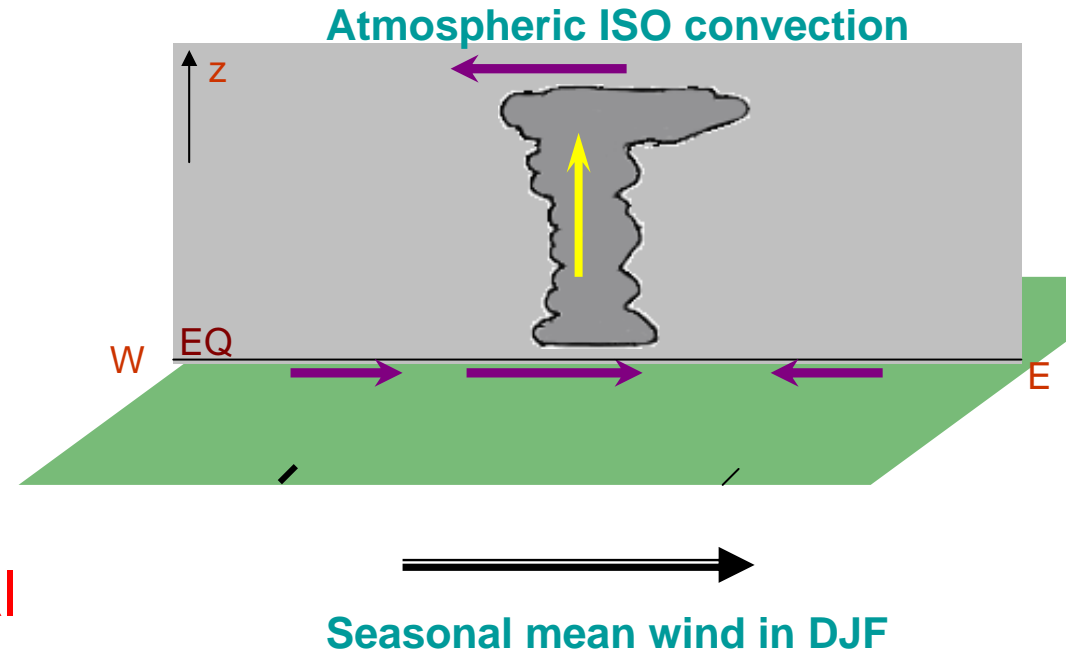
SON



Q2: Why is the SST variability strongest in boreal winter?

Hypothesis: Seasonal dependence of intraseasonal SST variability is caused by summer-winter differences in

1. background mean zonal wind
2. strength of the ISO forcing
3. ocean mixed layer depth

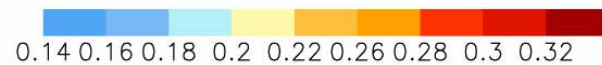
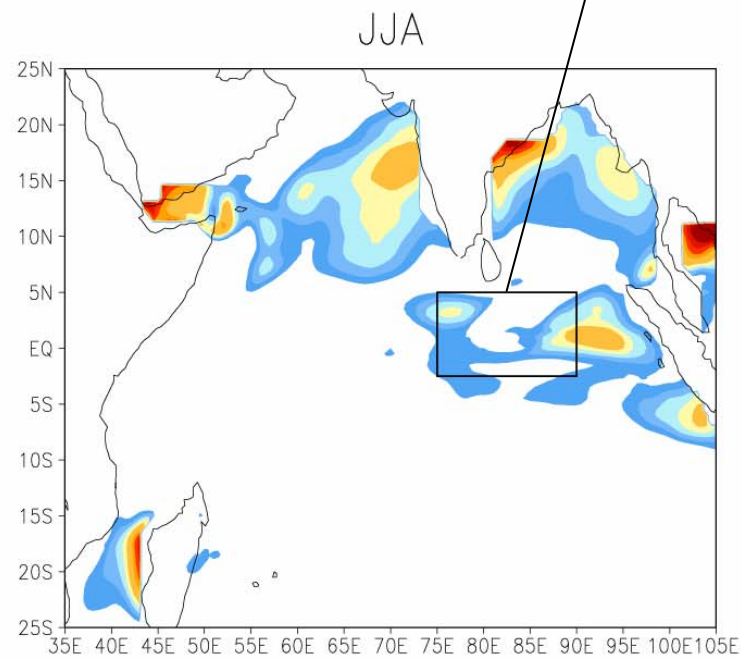
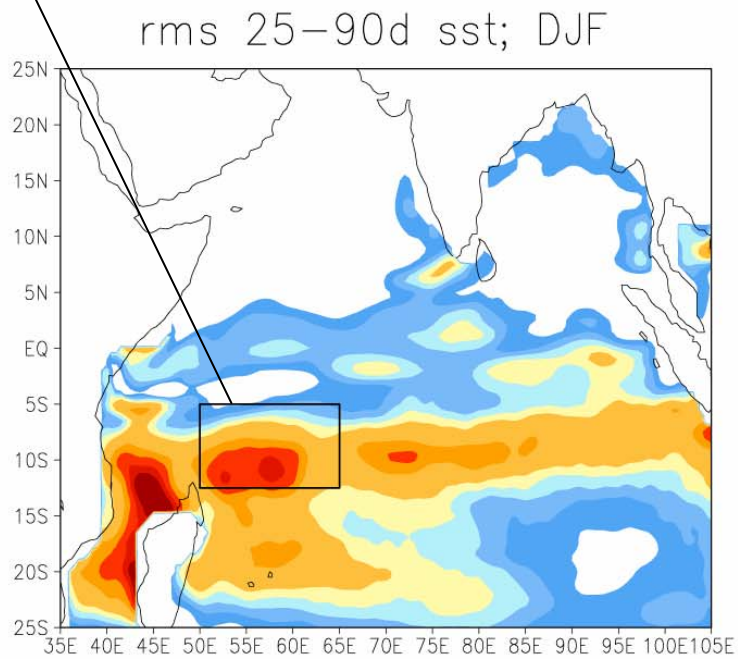
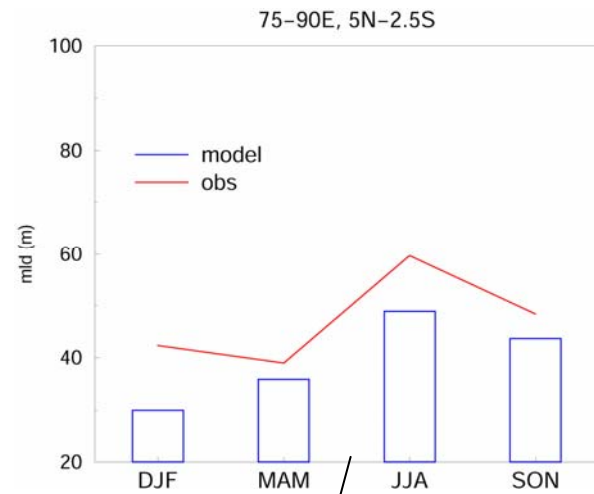
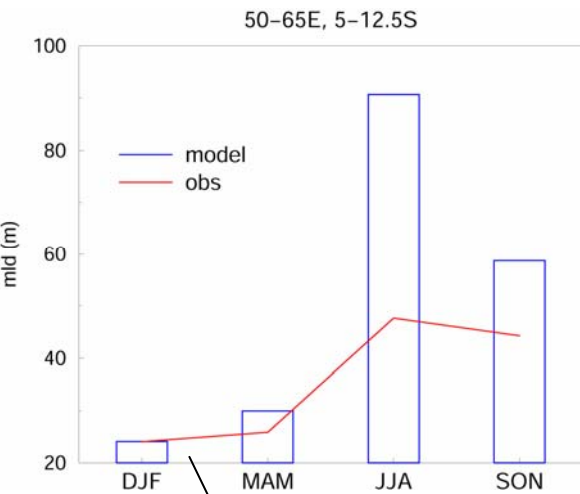


SST tendency is mainly affected by

- Short wave cloud forcing
- Latent heat flux/ocean mixing

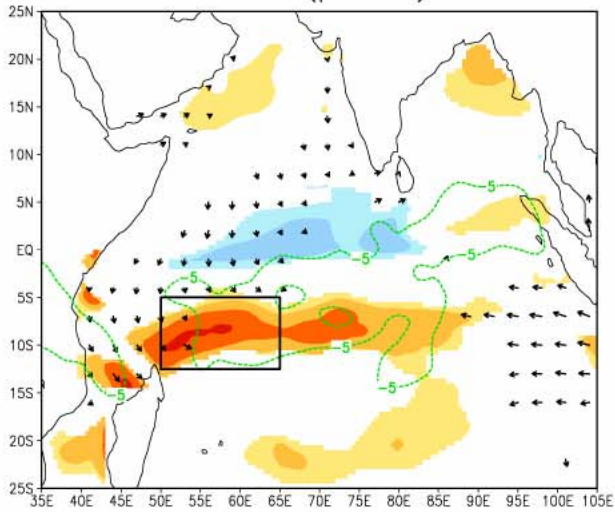
Experimental setup

- 2.5 layer ocean model (Wang, Li, and Chang 1995; Fu and Wang 2001)
- Integrate the model for 15 yrs (1987-2001) using ERA40 daily (heat flux and wind stress) data

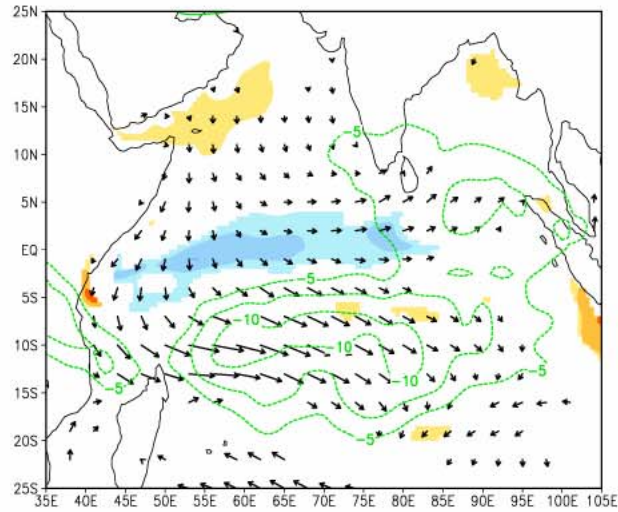


25–90d SST,tau,OLR–tx reg, DJF

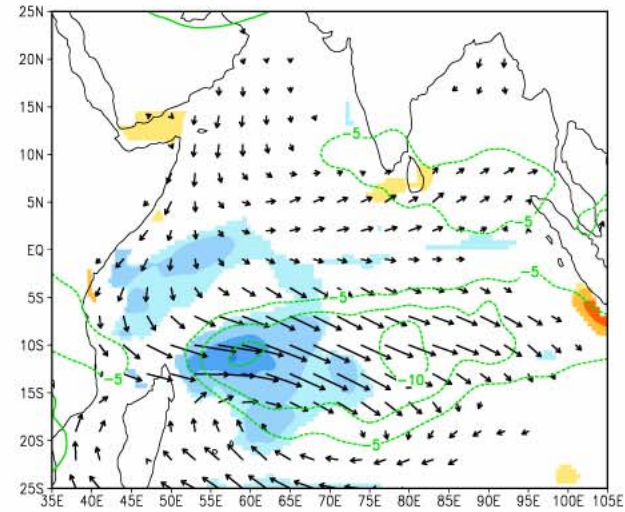
t=-2 (pentad)



t=-1

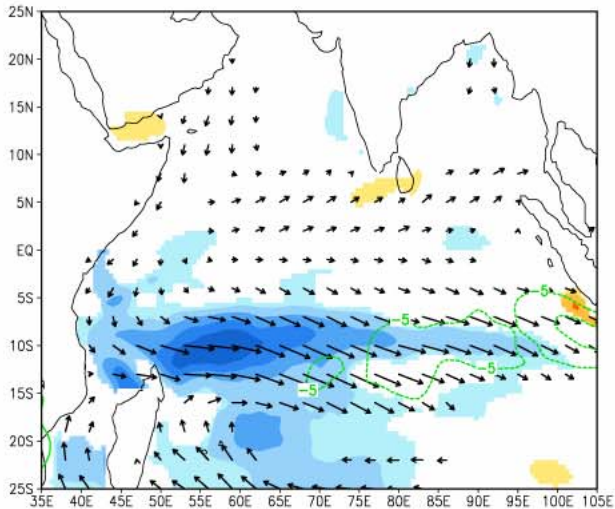


t=0

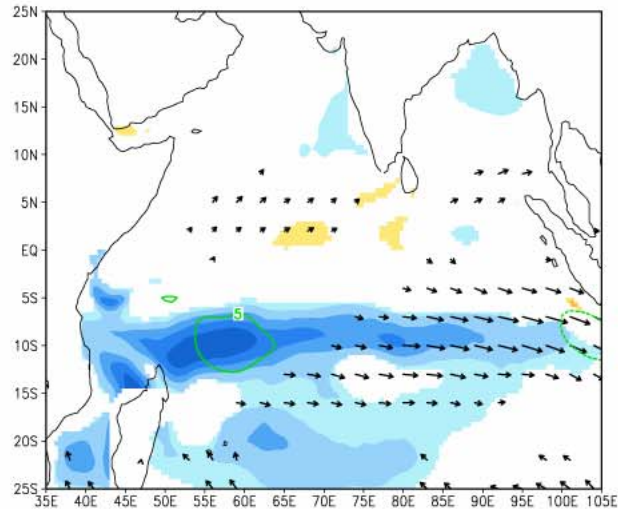


0.25

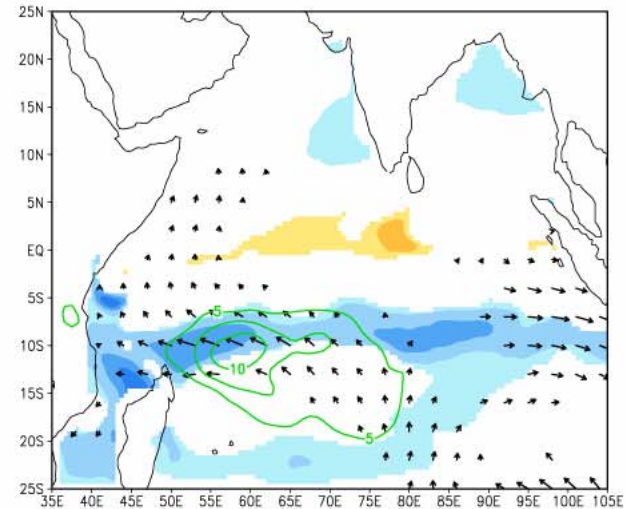
t=+1



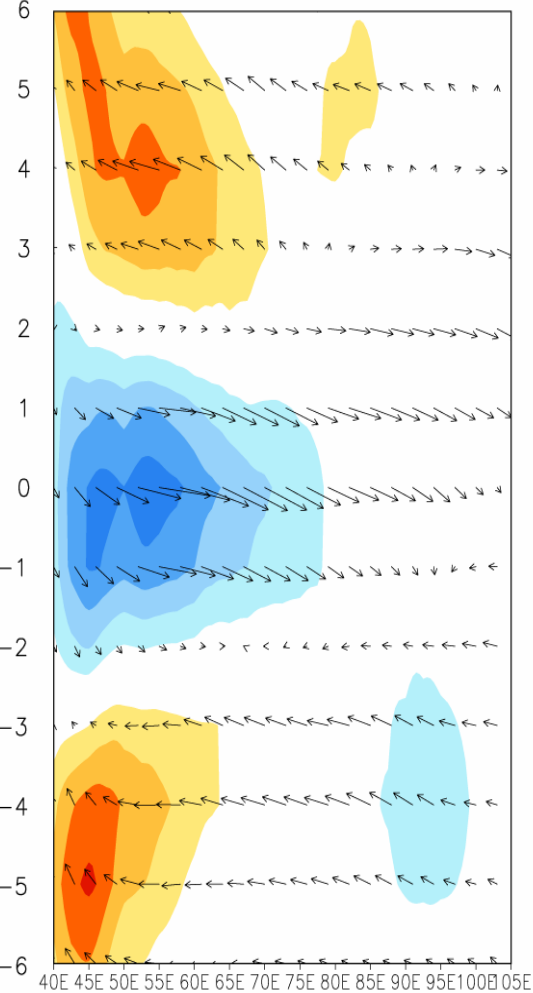
t=+2



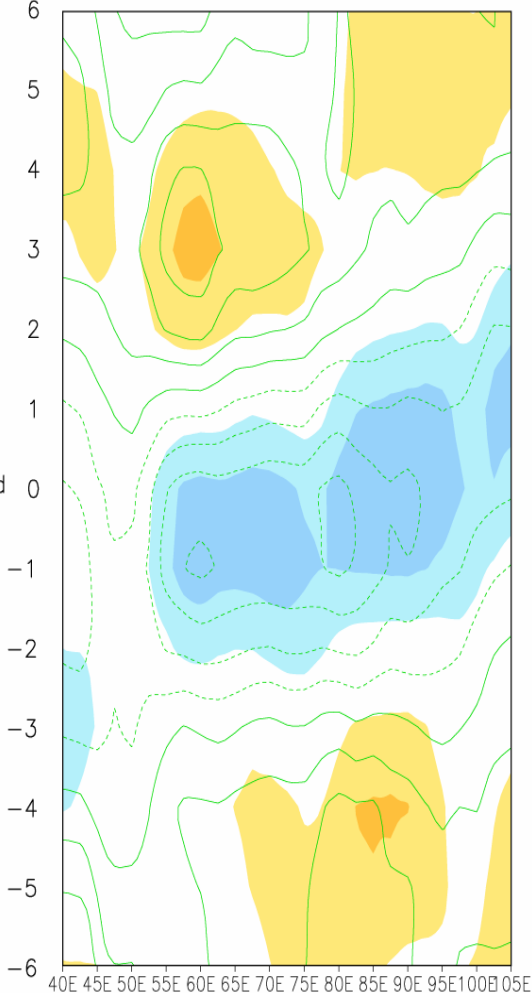
t=+3



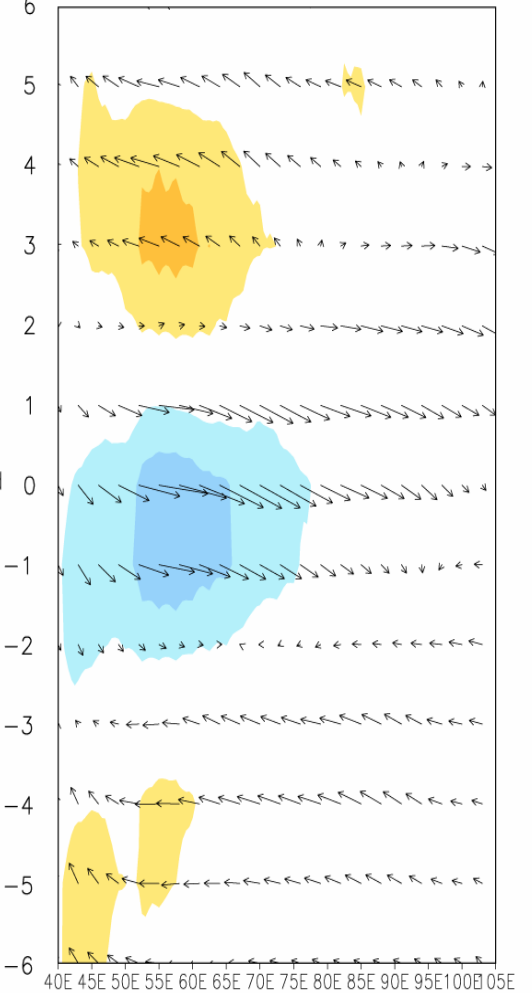
12.5–7.5S -QLH'/h,tau; DJJ



12.5–7.5S -QSW'/h,OLR; DJF

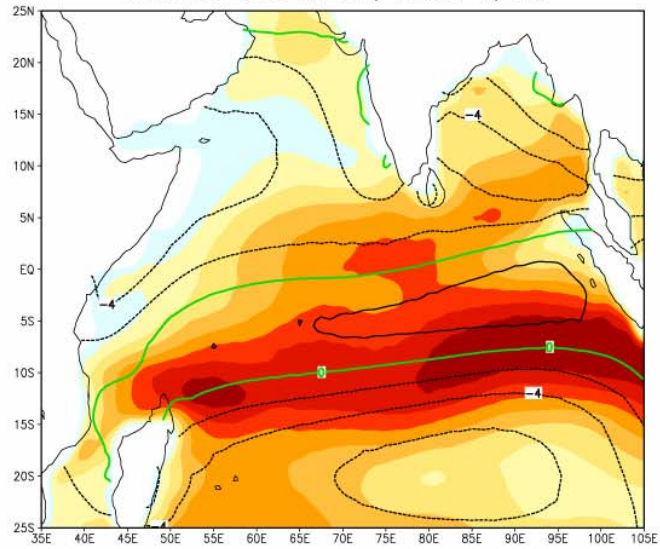


12.5–7.5S entrainment; DJF

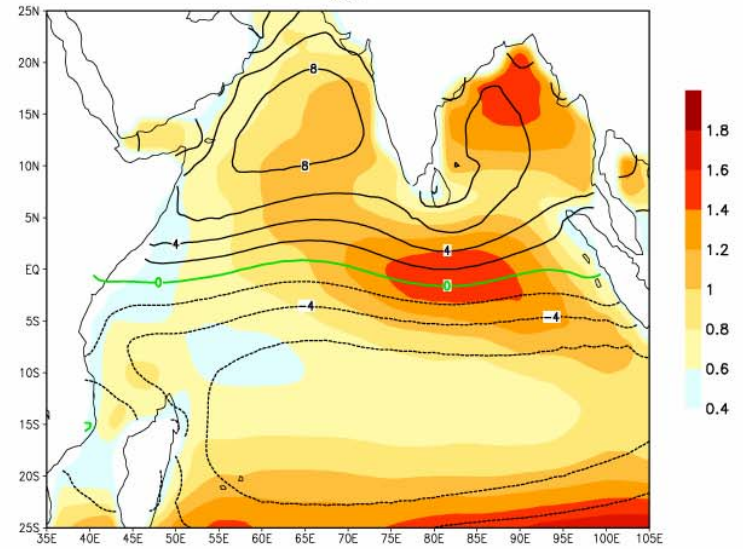


Heat budget: latent heat vs. short wave vs. vertical entrainment

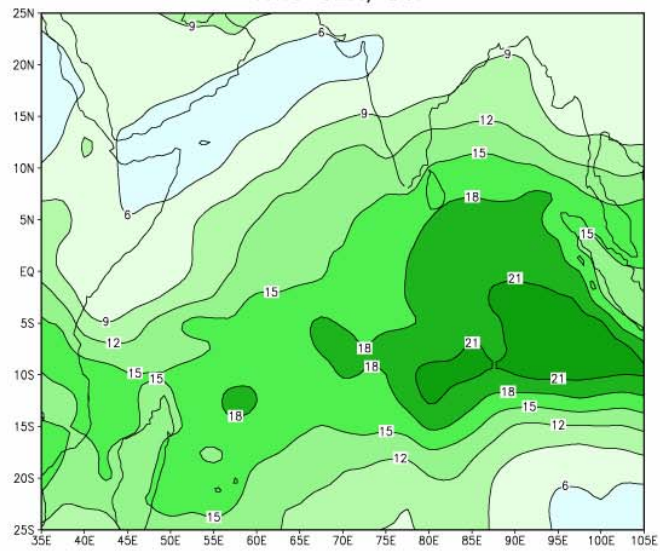
rms 25–90d u10m, mean u; DJF



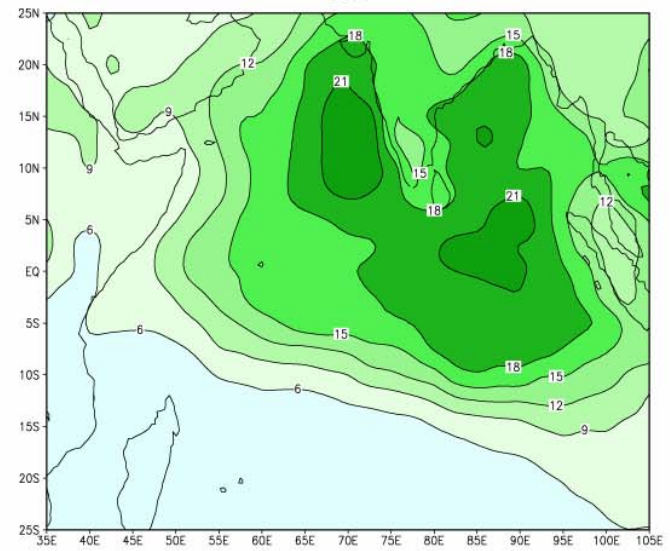
JJA



rms OLR; DJF



JJA



Summary 2: Seasonality of intraseasonal SST variability in IO

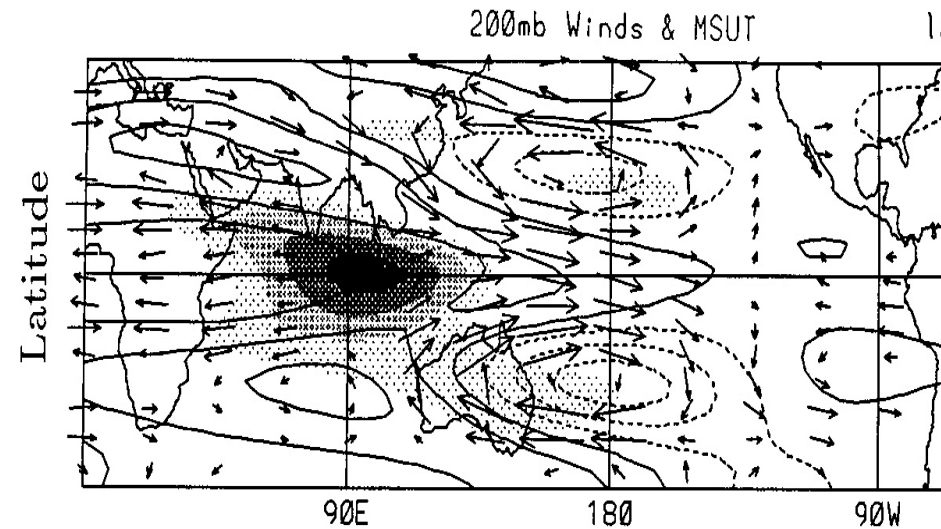
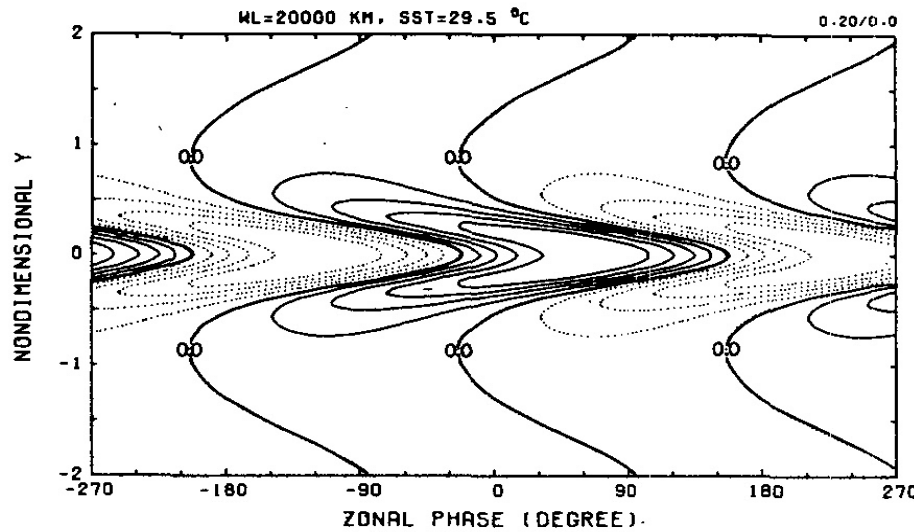
- ✚ Geographic location of the IO thermocline dome determines where maximum SST variability appears – south of the equator.
- ✚ The mean westerly along the ITCZ south of the equator in boreal winter leads to an in-phase relationship between the latent heat flux and short wave radiation anomalies, and thus determines when the strongest SST variability occurs.
- ✚ The annual cycles of the ocean MLD and ISO forcing itself further magnify the summer-winter difference in the intraseasonal SST variability.

Horizontal structure of frictional coupled Kelvin-Rossby mode

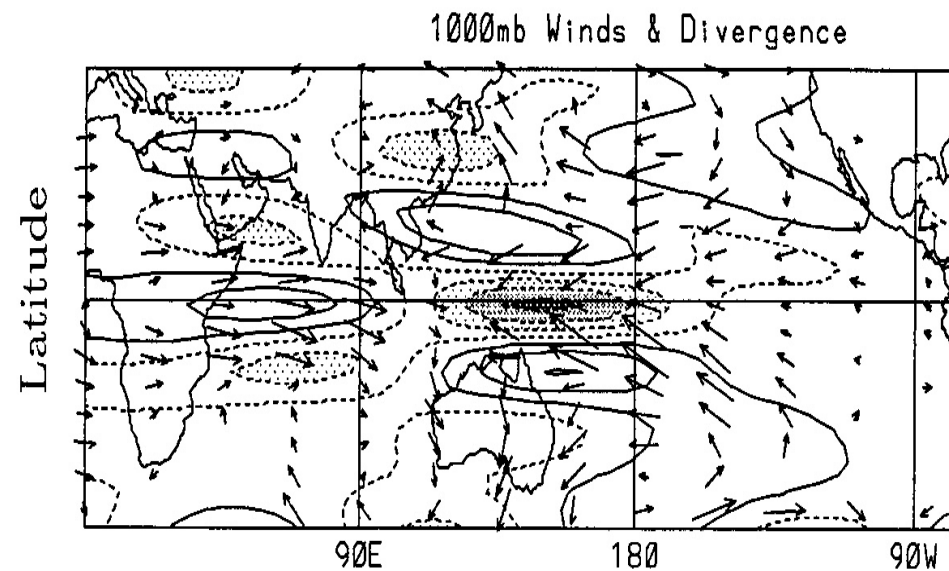
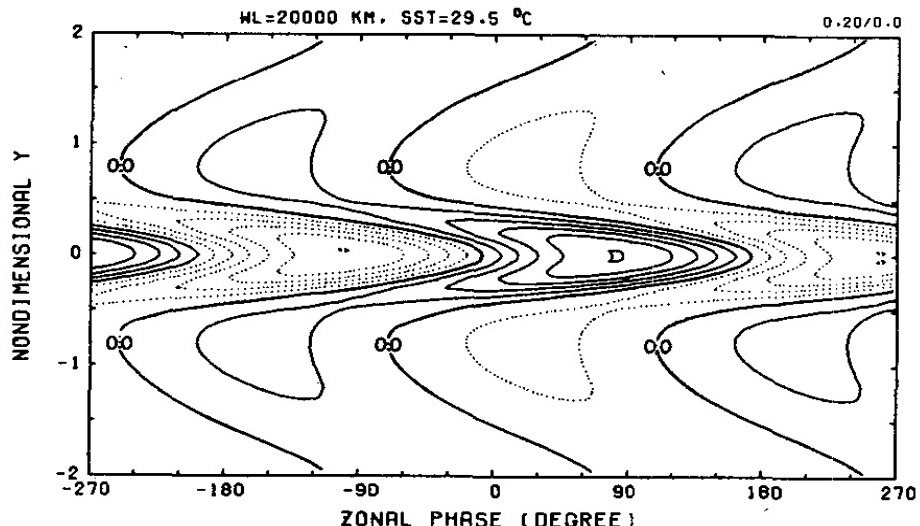
Unstable Normal mode (Model)

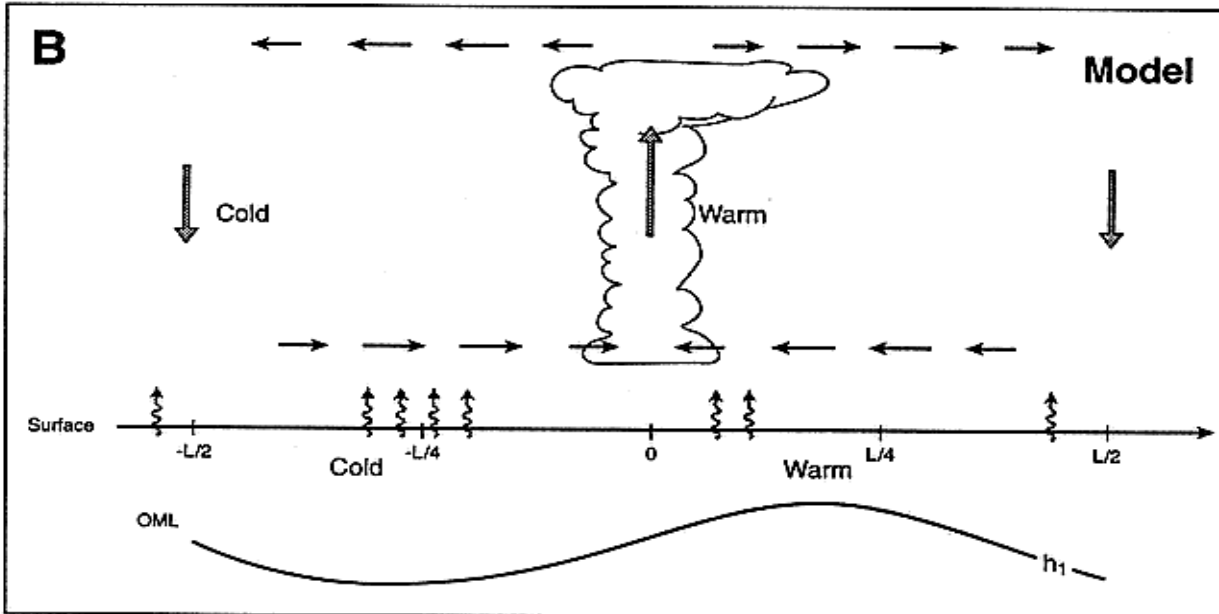
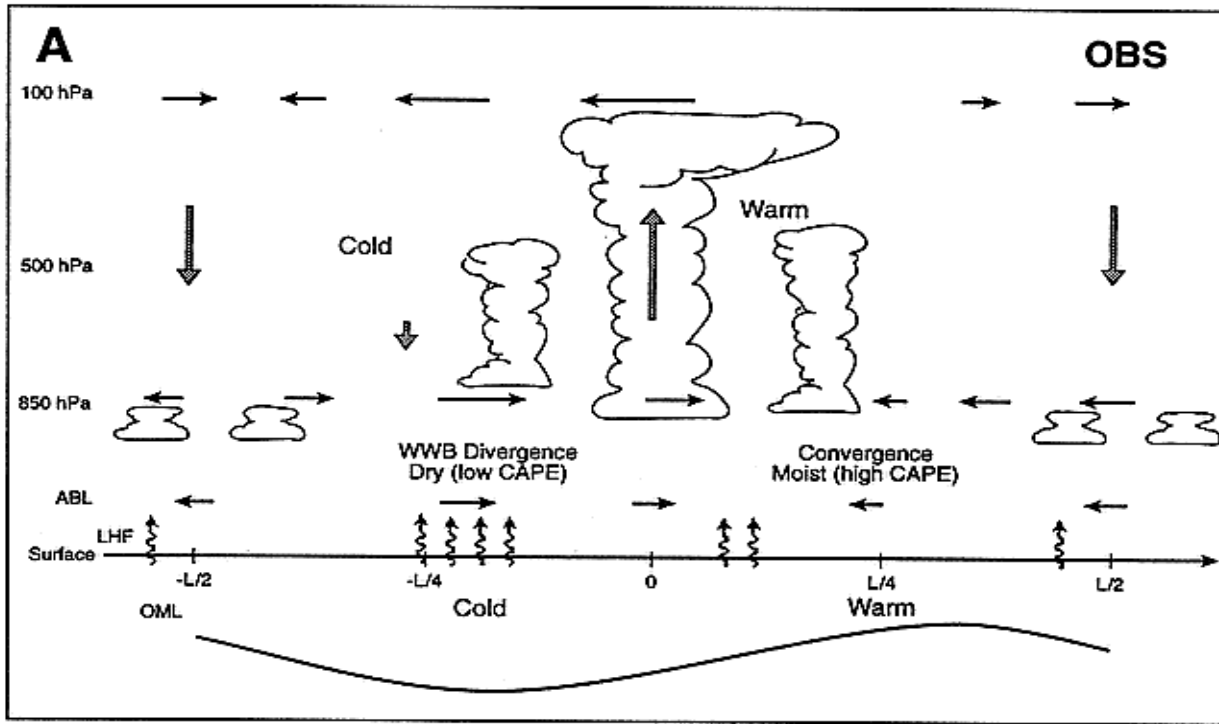
Hendon and Salby 1994 (OBS)

(d) VERTICAL MOTION FIELD AT MIDTROPOSPHERE



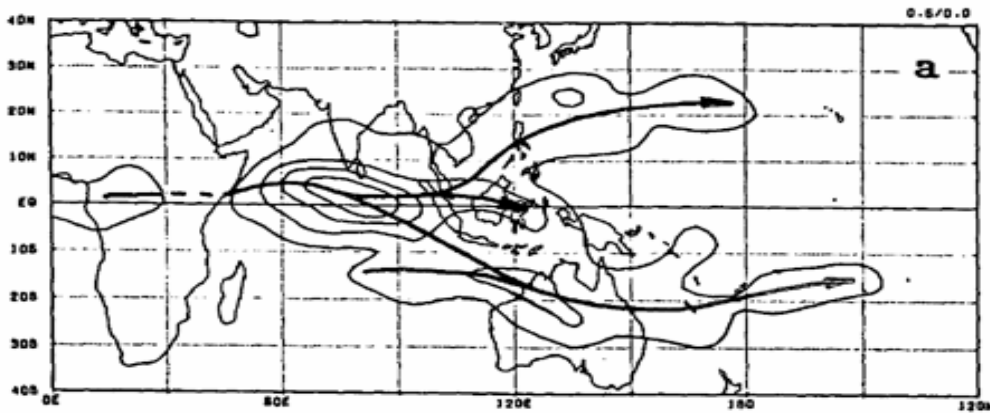
(e) VERTICAL MOTION FIELD AT p_0





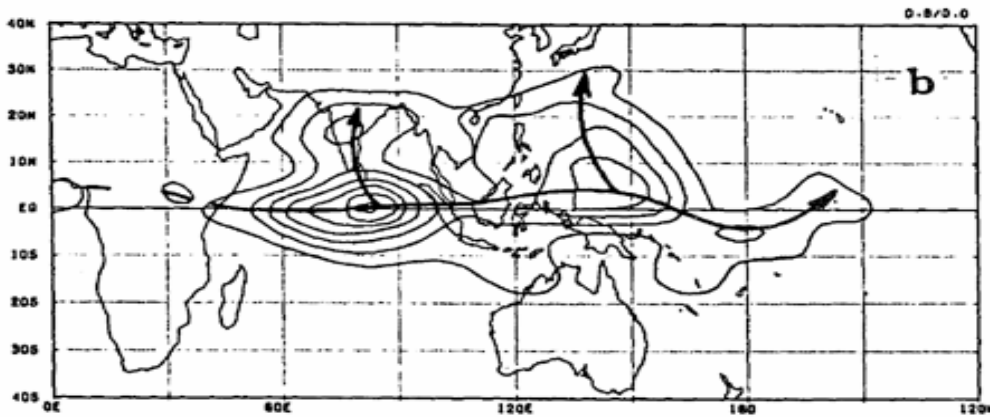
Schematic diagram illustrating the equatorial vertical structure of the Madden-Julian Oscillation observed in TOGA COARE (a) and the most unstable mode in the coupled atmosphere-mixed layer ocean model (b).

The observations are based on Chen et al. (1991), Sui et al. (1996), [Zhang \(1996\)](#), [Lin and Johnson \(1996\)](#), Jones and Weare (1991), [Fasullo and Webster \(1995\)](#), and [Chou et al \(1995\)](#).



Propagation of 122 TICA events classified into 3 categories:

(a) and (b) eastward (65%),
(c) independent northward (20%)
and westward (15%).



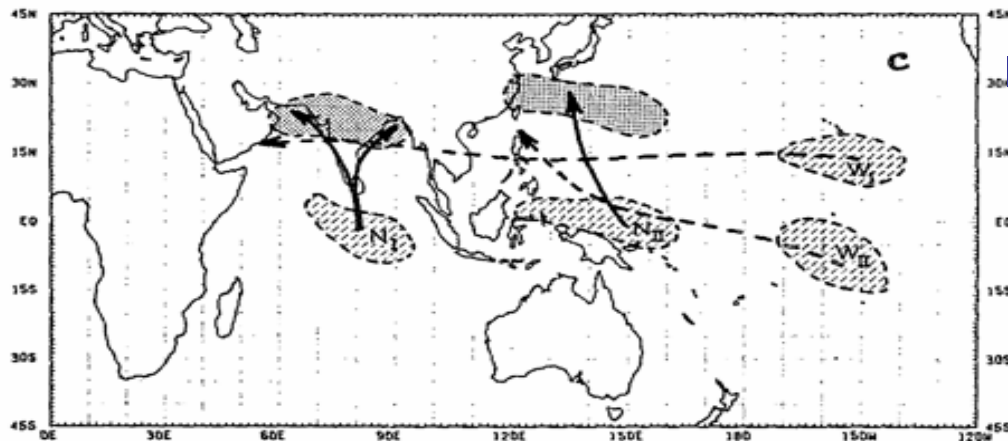
■ Among the eastward cases:

EE: 42% (a)

N(S)E: 32% (a)

EN: 26% (b)

■ The eastward propagation is active in boreal winter (Nov-Apr)



■ The independent northward and westward propagation occur in boreal summer (May to Oct).

Wang and Rui 1990