

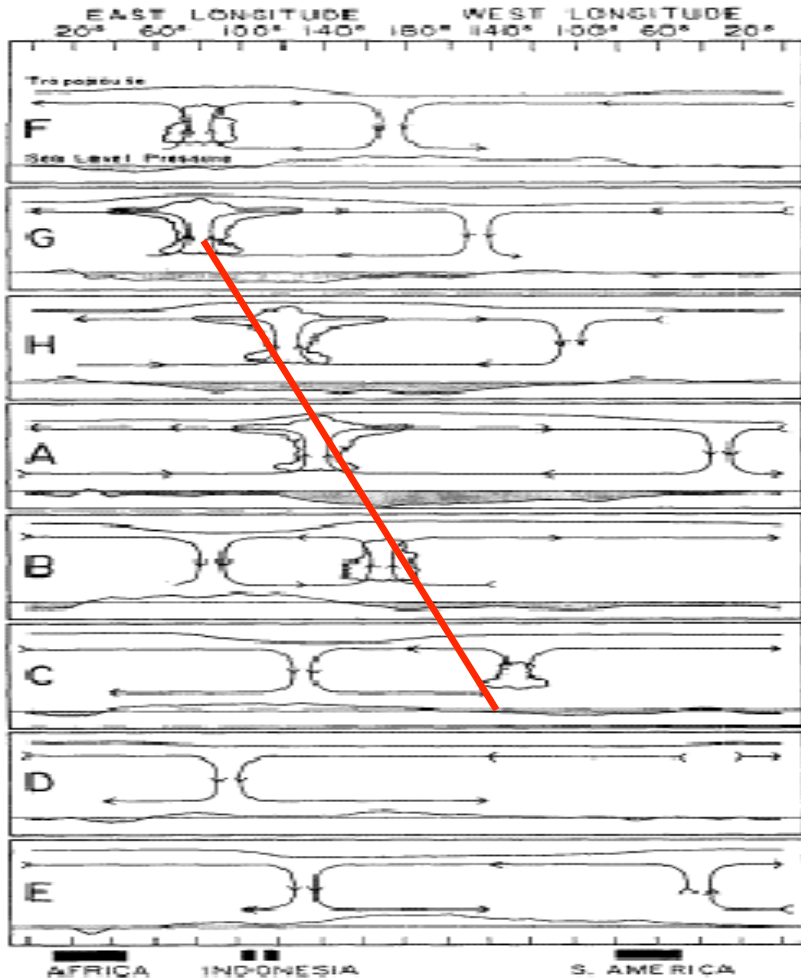
On the Initiation of the Madden-Julian Oscillation (MJO)

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Rosenstiel School of Marine and Atmospheric Sciences (RSMAS)
University of Miami

Busan, South Korea, 18th June 2010

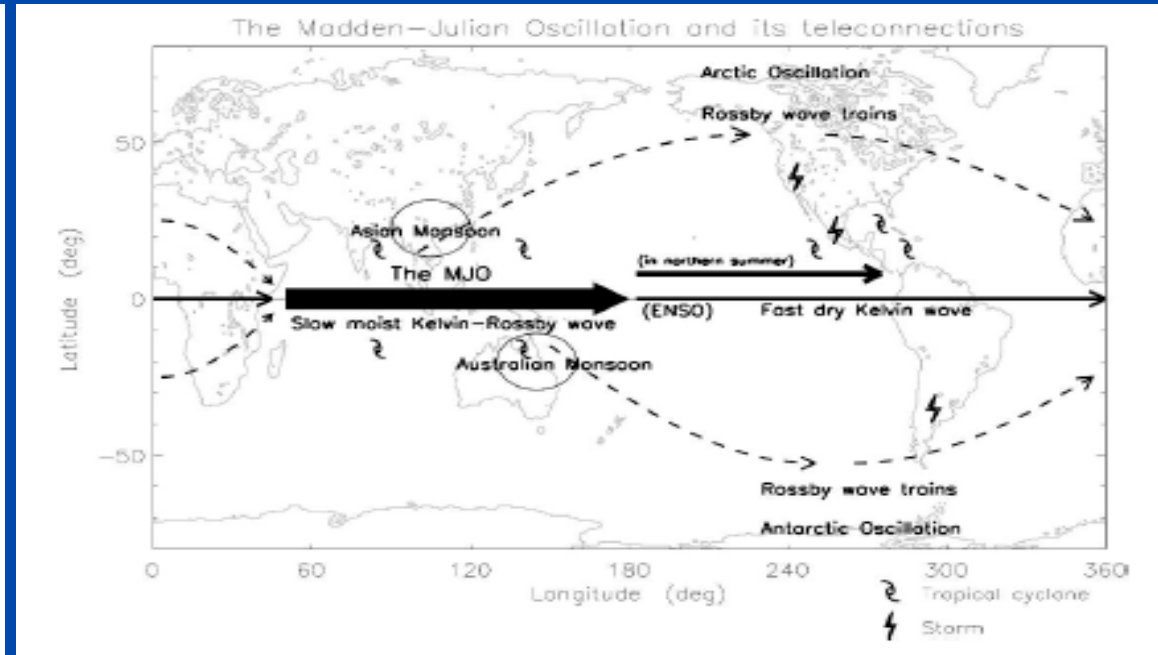
Background

Longitude-height Structure



Madden and Julian (1972)

Teleconnections



Lin et al. (2006)

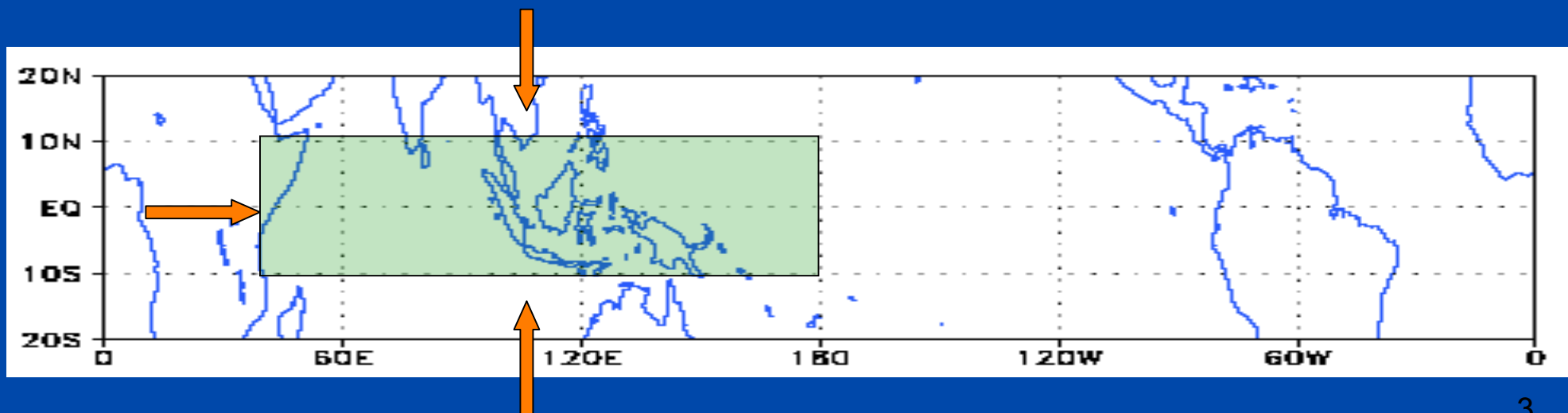
Time period: 30-70 days
Propagation speed: 5 m/s
First-mode baroclinic structure

Motivations

- What is the mechanism of the MJO initiation?
- How different parameters affect the MJO initiation?

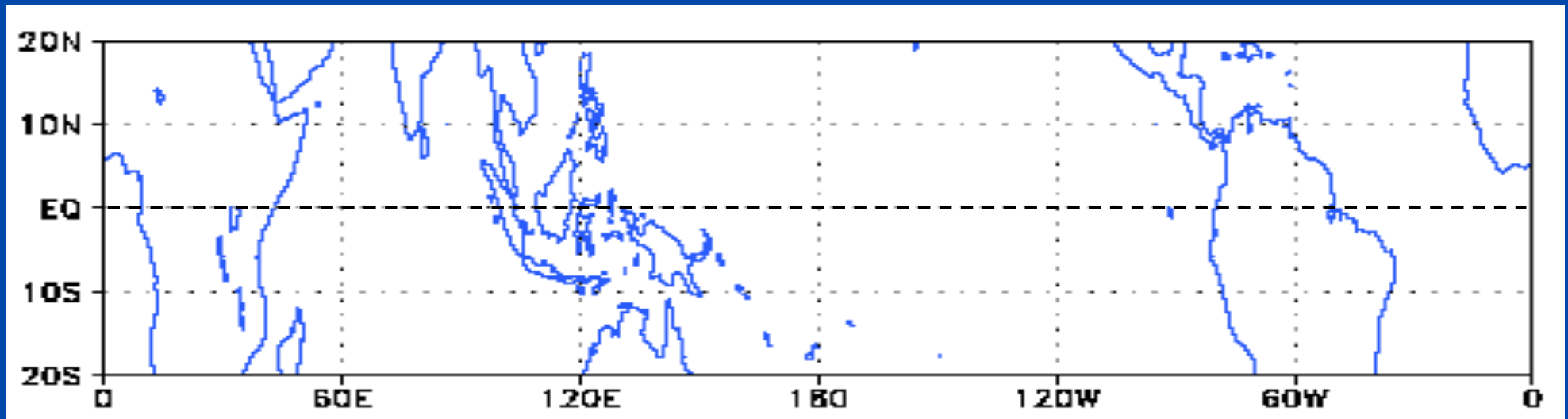
Proposed Mechanisms of the MJO Initiation

- Discharge-recharge mechanism (i.e. tropical internal dynamics)
- Initiation by circumnavigating waves (i.e. from previous MJO event)
- Extra-tropical influences
- Stochastic forcing



A New Approach

- Use a unique model, i.e., a Tropical Channel Model.
- Start with the full physics, and then test one factor at a time.
- Make the problem more tractable by doing sensitivity tests on the parameters (e.g., lateral boundaries), and not by testing the mechanism (e.g., extratropical forcing) directly.
- Case study



Outline

The Initiation of the MJO :

- Background and Motivations
- **Model and Data**

Tropical Channel MM5 (TMM5) : Case Study

Tropical Channel WRF (TWRF) : Statistics and Case Study

- Results

Sensitivity to the SST, Initial Conditions, Convection-

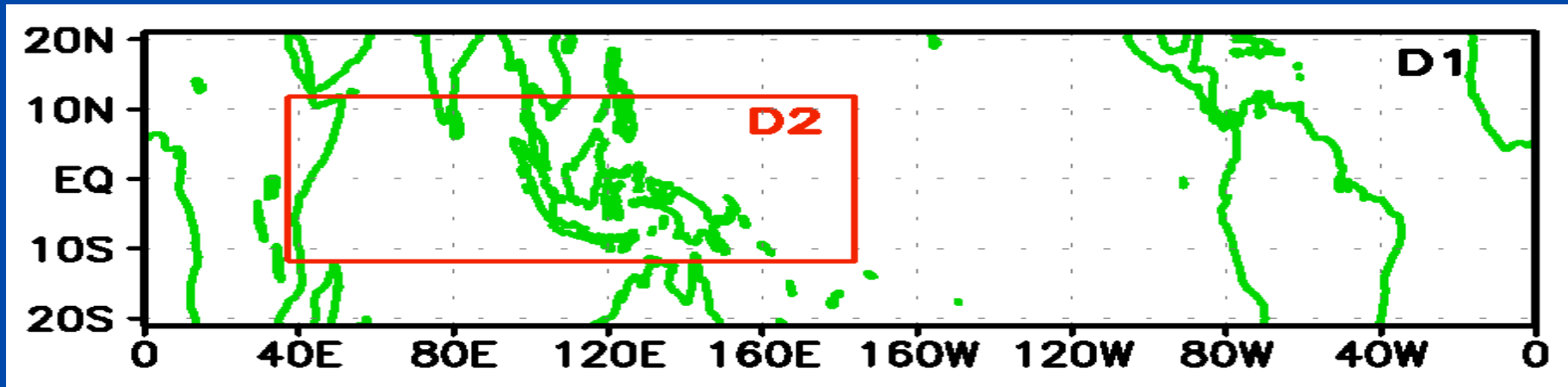
Circulation Interactions and the Boundary Conditions

Mechanism for the Extratropical Influence

MJO Statistics and Cases in Climate Simulations

- Implications and Summary

Model and Data



Tropical Channel MM5 (TMM5) : D1 : 111 km, D2 : 37 km

data : NCEP 'FNL' data (1x1, 6 hourly)

moisture scheme : Simple Ice

time step: 3 minutes

cumulus scheme : Betts-Miller

model output: 3 hourly

radiation scheme : RRTM

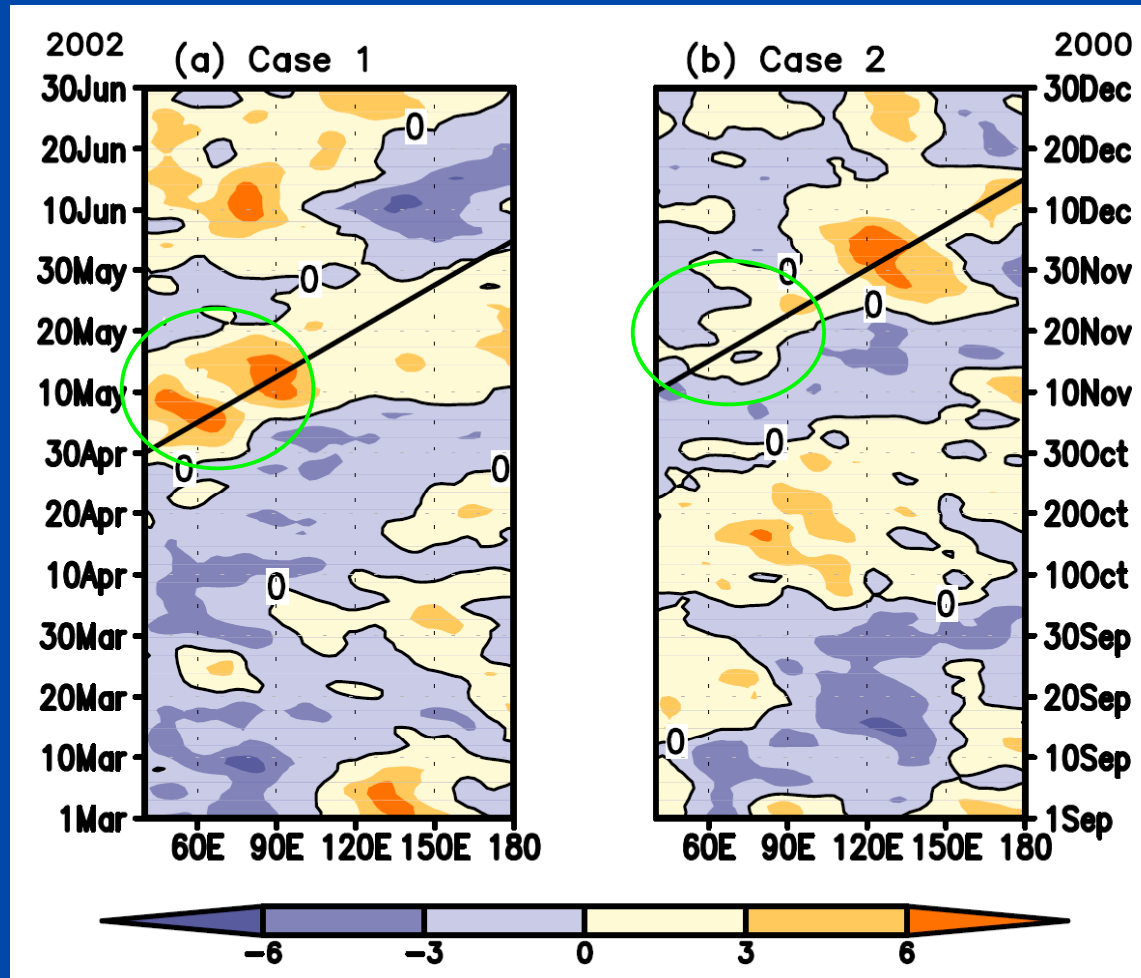
• More than 30 tests were performed to choose the set of schemes

Choice of the MJO Events

Apr-May 2002

Nov-Dec 2000

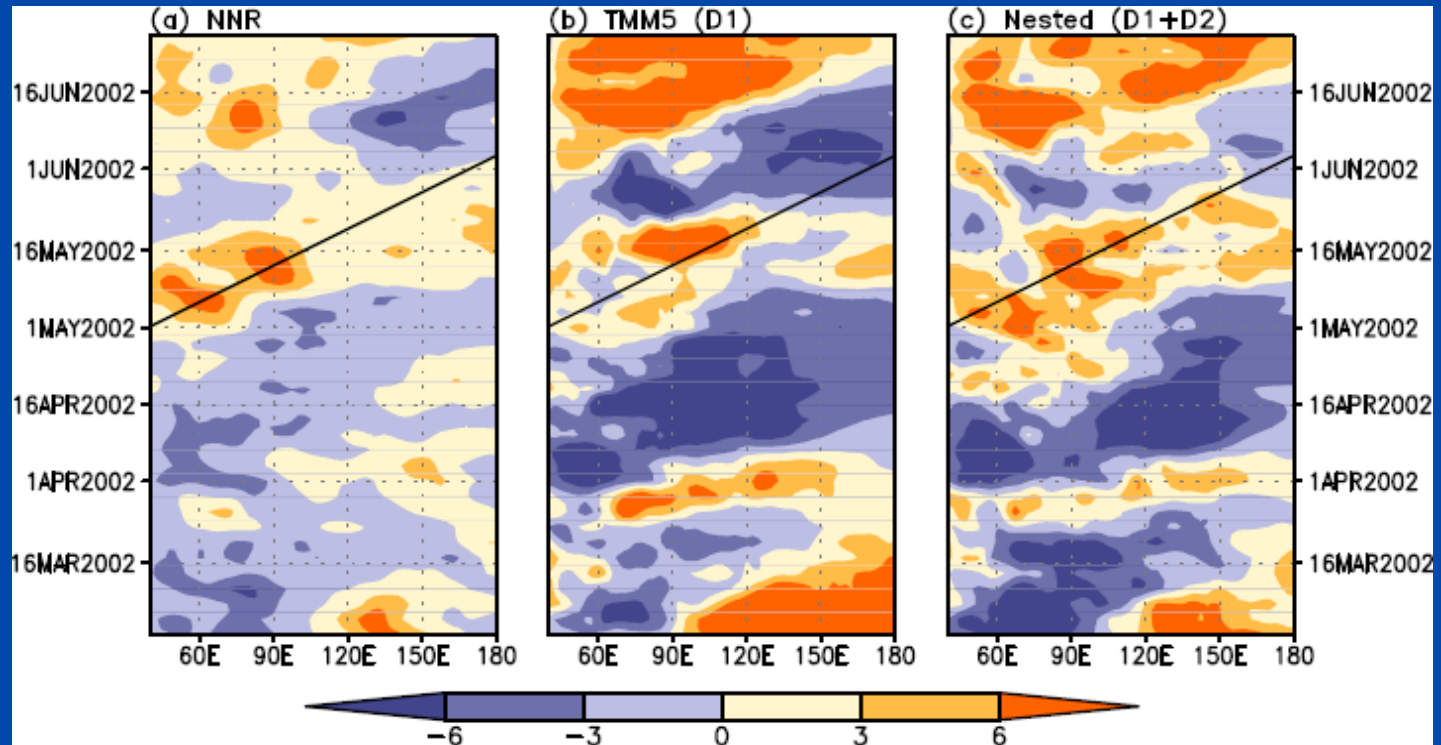
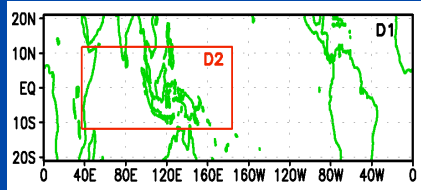
U850
Reanalysis



- Randomly chosen with different background SSTs.
- MJO initiation is defined wrt U850.

Model Validation

U850



(a) Reanalysis

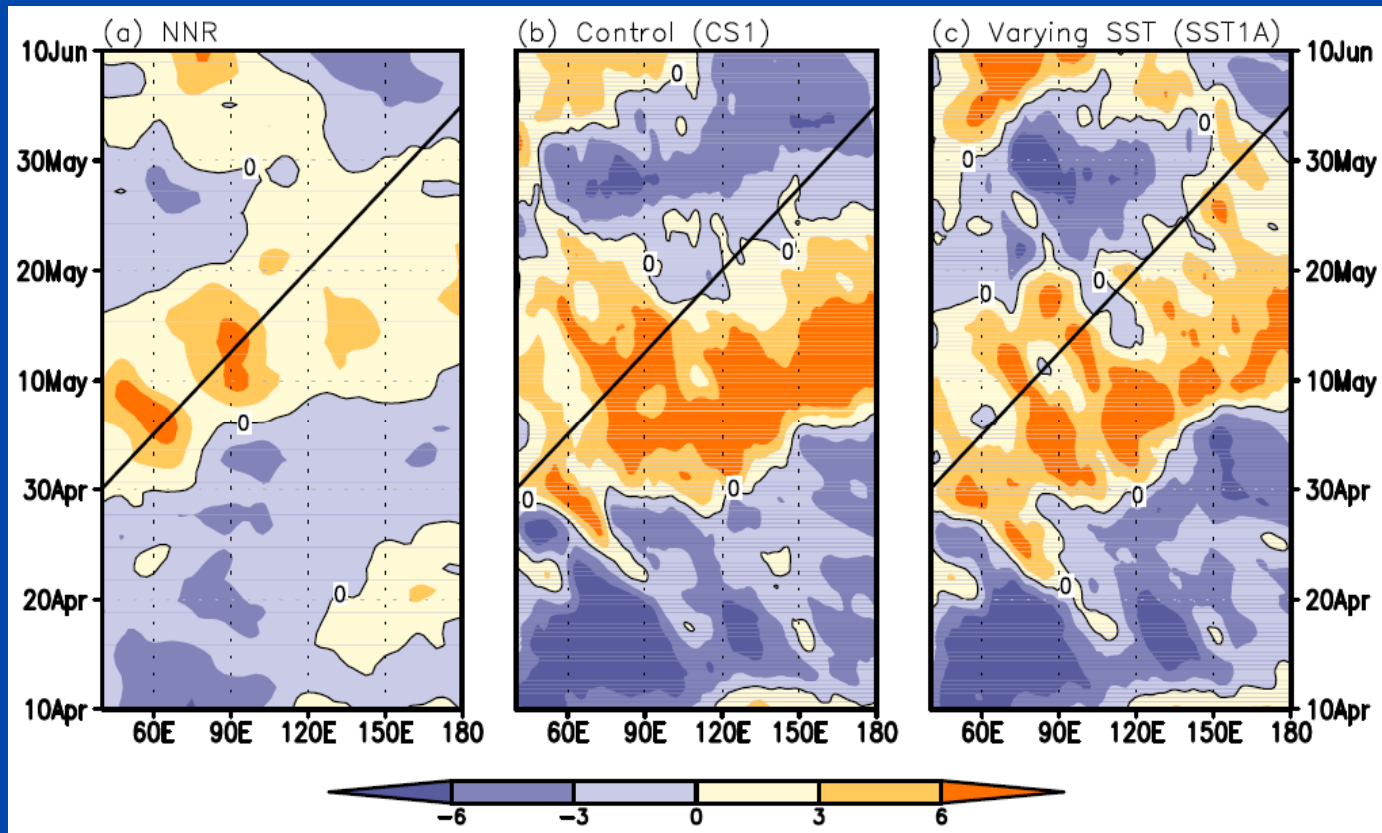
(b) Single domain

(c) Nested domain

- MJO initiation is captured two months after the model initial time.
- Cannot be attributed to the model initial conditions.
- Control simulation uses constant SST with one domain only.

Role of the SST (Case 1 : May 2002)

U850



(a) Reanalysis

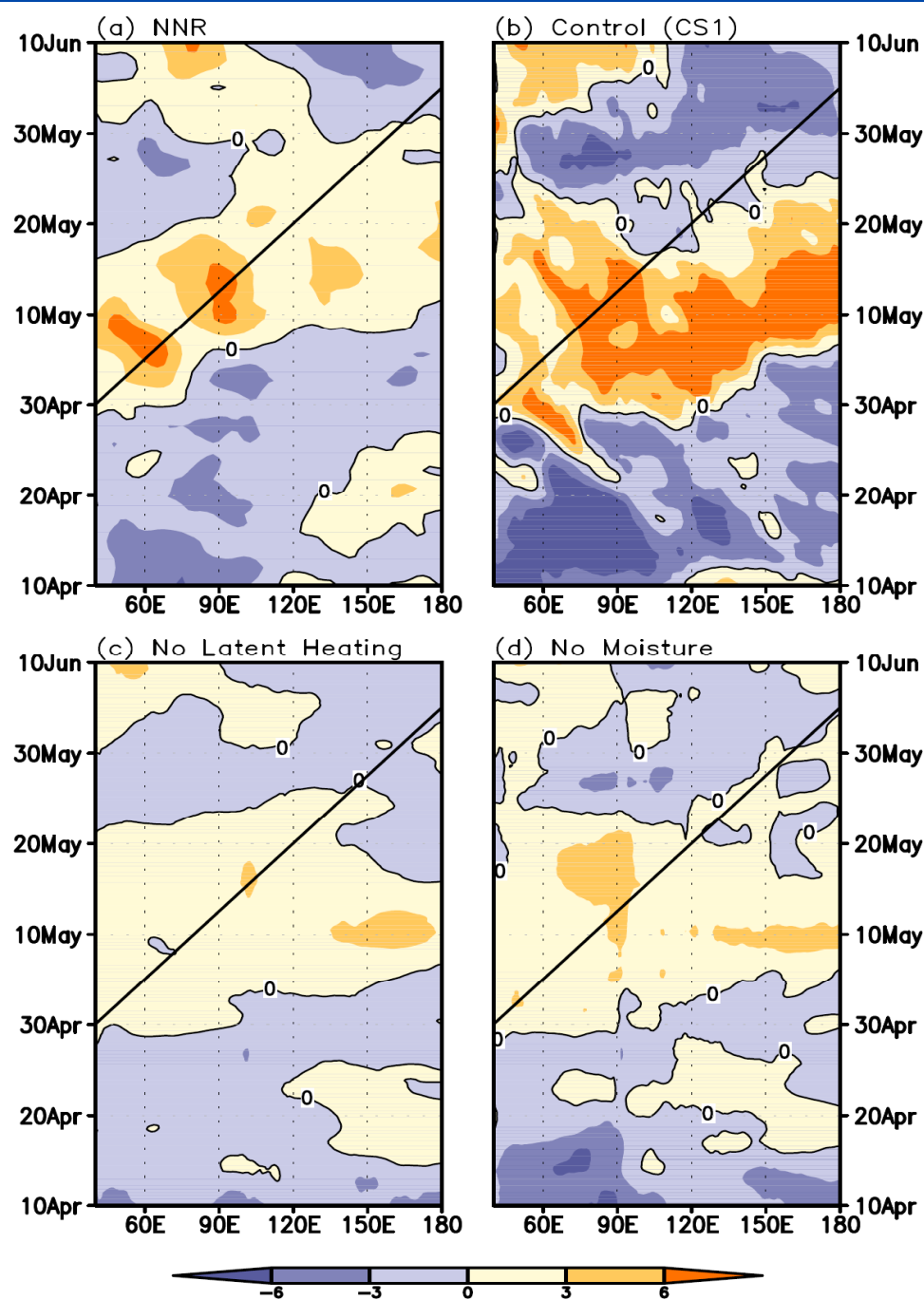
(b) Control

(c) Varying SST

- Intraseasonally varying SST is not a determining factor.
- Consistent for Case 2 (November 2000 MJO event).
- Stochastic Forcing with time-scale < 6 hr. from lateral boundaries do not play any role.

Role of the Moist Processes

Reanalysis



Control

➤ Moist processes are crucial for the strength & propagation, but not for the initiation.

No latent heating

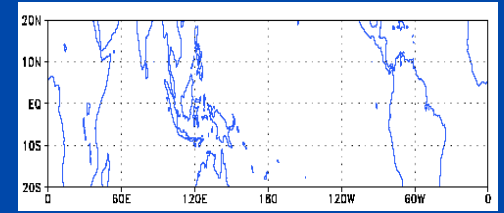
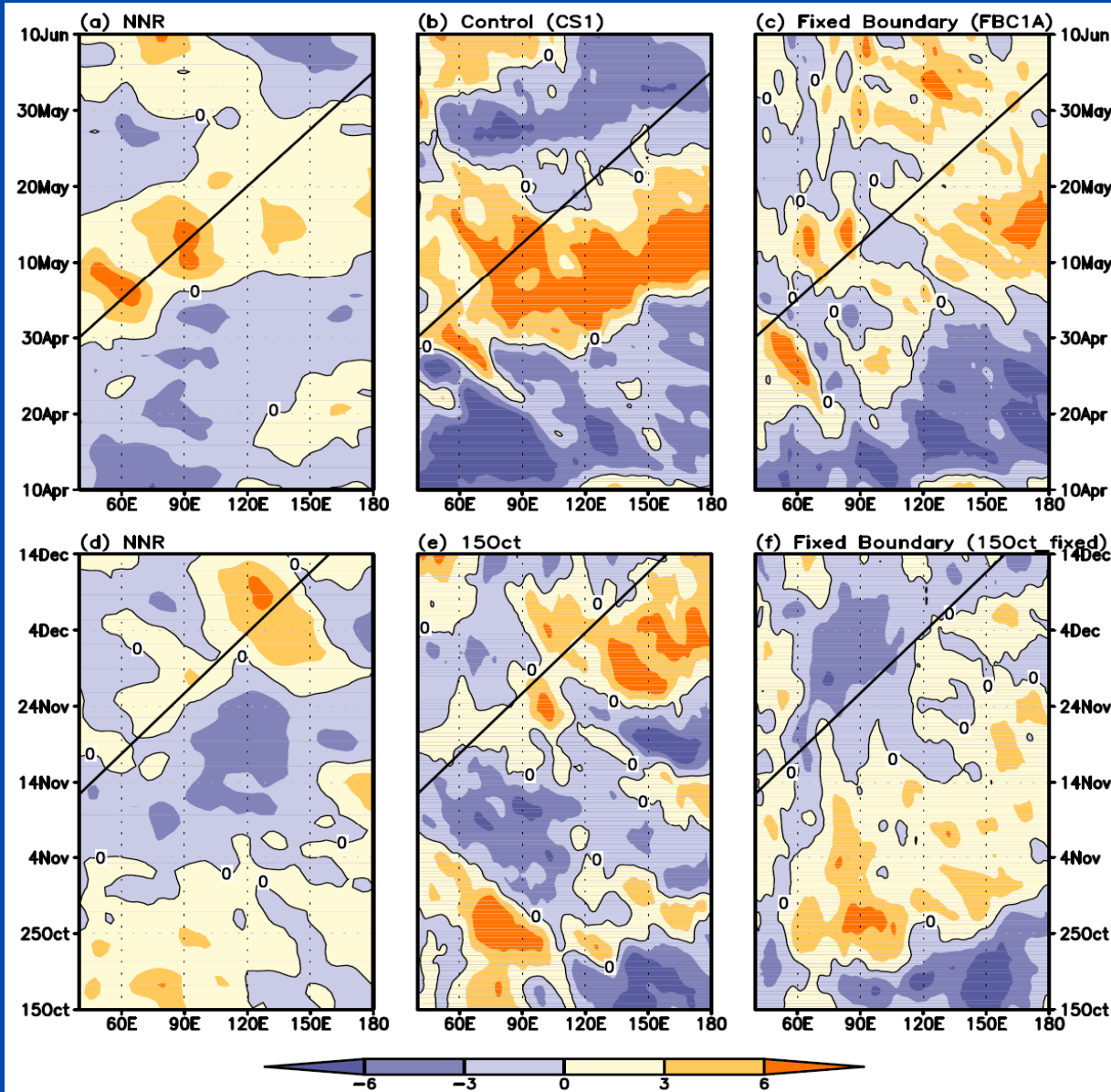
No moisture

➤ Consistent results by Lin et al. (2007) and Monier et al. (2009).

➤ Lateral boundary conditions are critical !

Sensitivity to the boundary conditions

Case 1



➤ Lateral boundary conditions are the only important factor.

➤ Are the lateral boundary conditions being forced by the MJO itself??

Case 2

(a) Reanalysis

(b) Control

(c) Constant Boundary

Sensitivity to the Boundary Conditions.....

- MJO is reproduced when model boundaries are further moved to 28SN and 38SN.
- Results are consistent for Case 2.
 - Lateral boundary conditions for these two cases represent extratropical, instead of MJO, influences.

Outline

The initiation of the MJO :

- Background and Motivations
- Model and Data
- Results

Role of the Initial Conditions and SST : No

Role of the Convection-Circulation Interactions : No

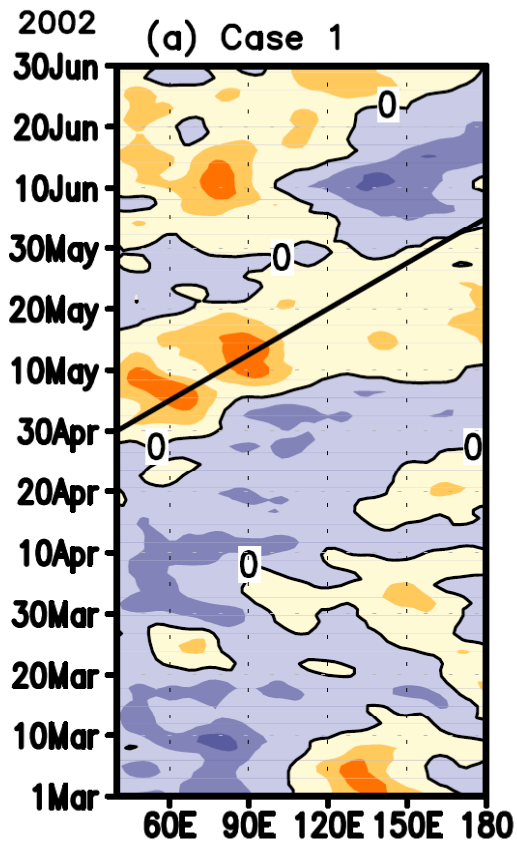
Sensitivity to the Boundary Conditions : Yes

Mechanics of the Extratropical Influence

MJO Statistics and Cases in Climate Simulations

- **Conclusions and Implications**

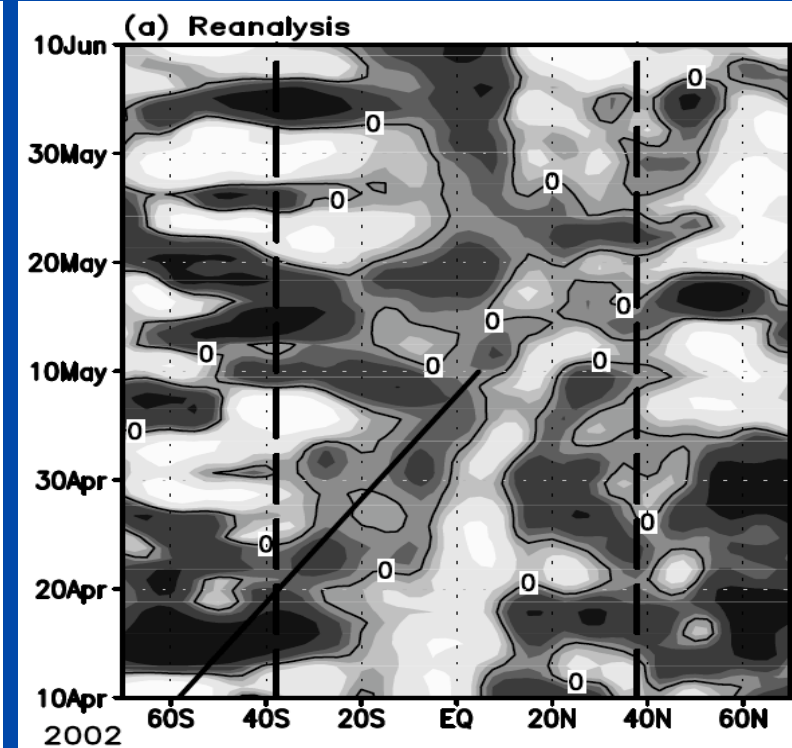
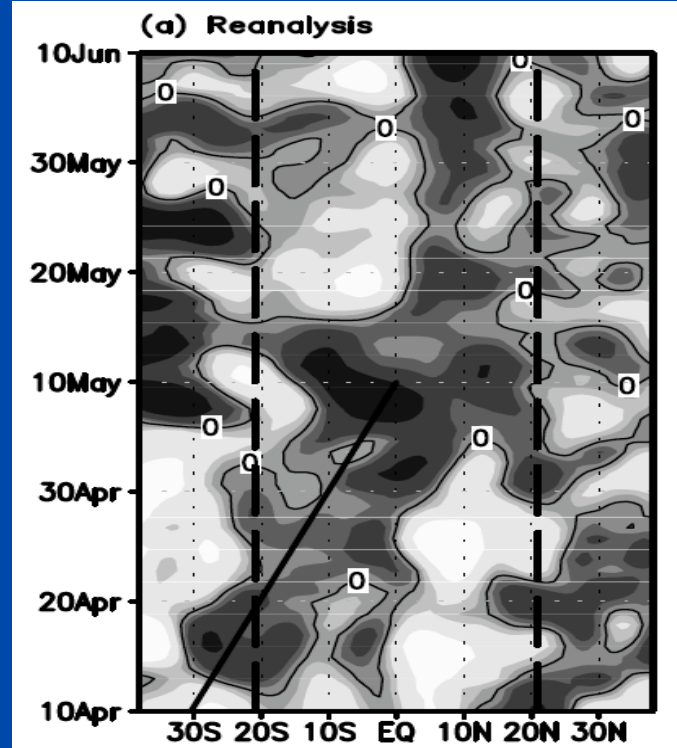
Evidence of extratropical influences (case 1: May 2002)



U850

(40E - 50E)

V850



- Valid at other levels (e.g., 925 hPa).
- Zonal momentum budget can quantitatively confirm this influence

Mechanics of the extratropical influences

- Lower troposphere: Zonal momentum budget

$$\frac{\partial u'}{\partial t} = -\frac{\partial \phi'}{\partial x} + fv' - \left(u \frac{\partial u'}{\partial x} + u' \frac{\partial \bar{u}}{\partial x}\right) - \left(v \frac{\partial u'}{\partial y} + v' \frac{\partial \bar{u}}{\partial y}\right) - \left(\omega \frac{\partial u'}{\partial p} + \omega' \frac{\partial \bar{u}}{\partial p}\right) + R'$$

u = zonal wind

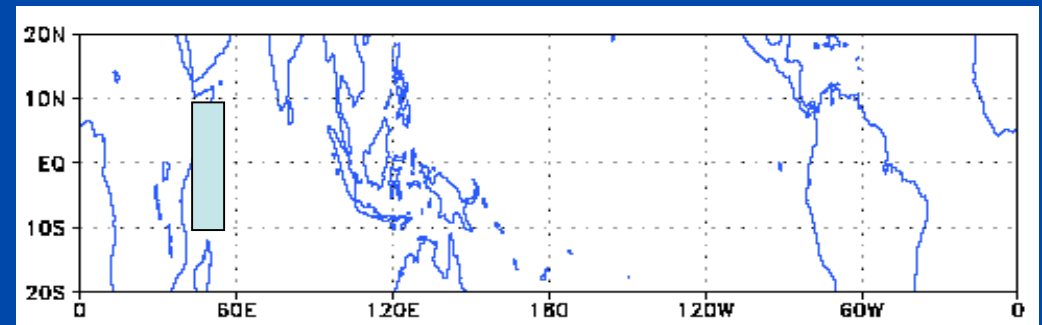
v = meridional wind

ω = vertical pressure velocity

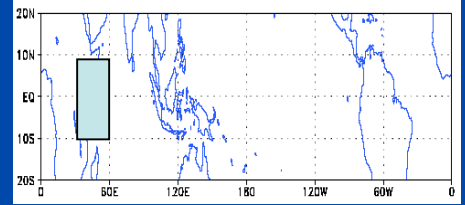
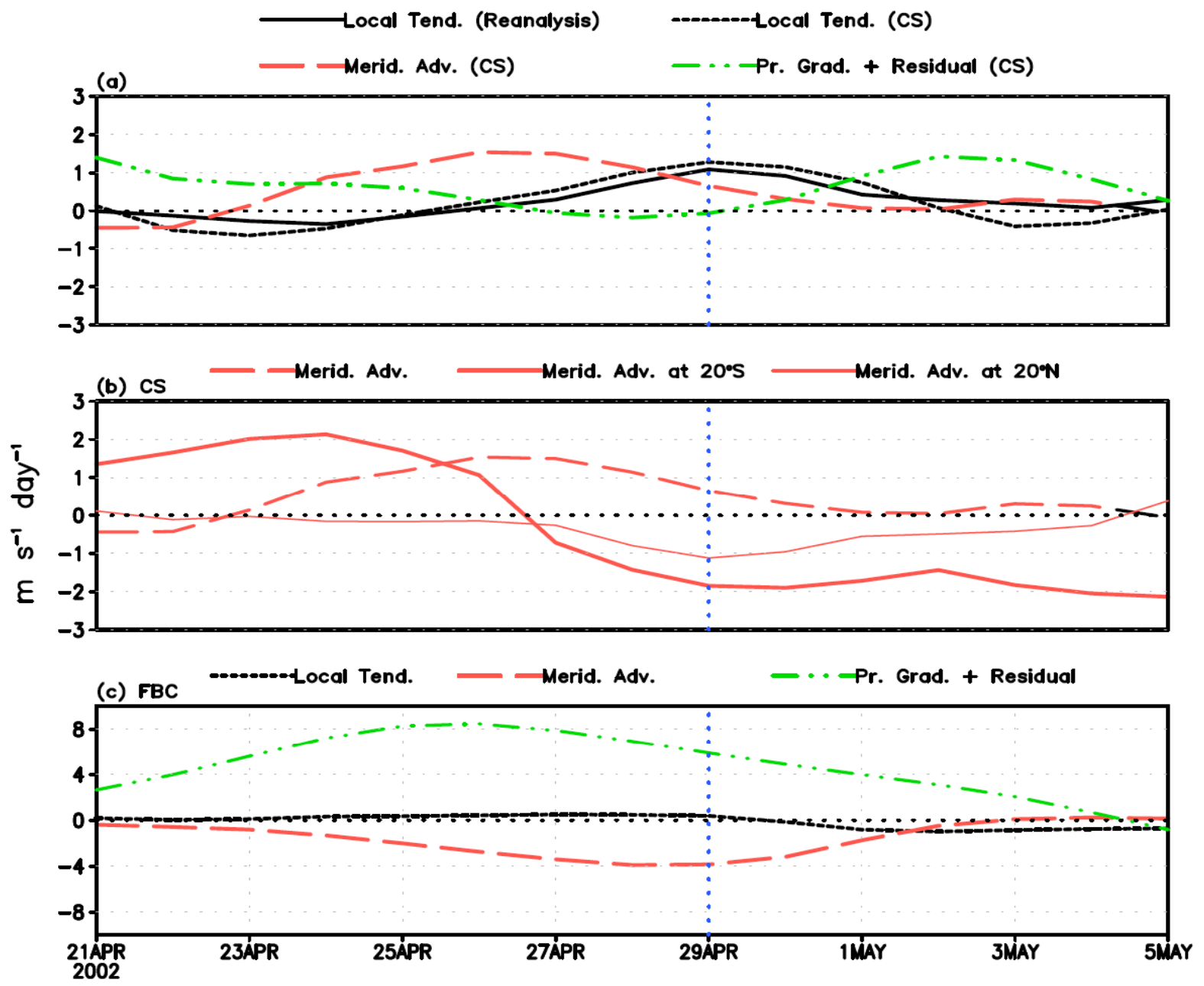
f = Coriolis parameter

Φ = geopotential

R = residual



Zonal Momentum Budget (10S-10N, 40E-50E)



• Meridional advection of zonal momentum is crucial at the lower troposphere.

$$\left(\bar{v} \frac{\partial u'}{\partial y} + v' \frac{\partial u'}{\partial y} + v' \frac{\partial \bar{u}}{\partial y} \right)$$

• What happens at the upper troposphere?

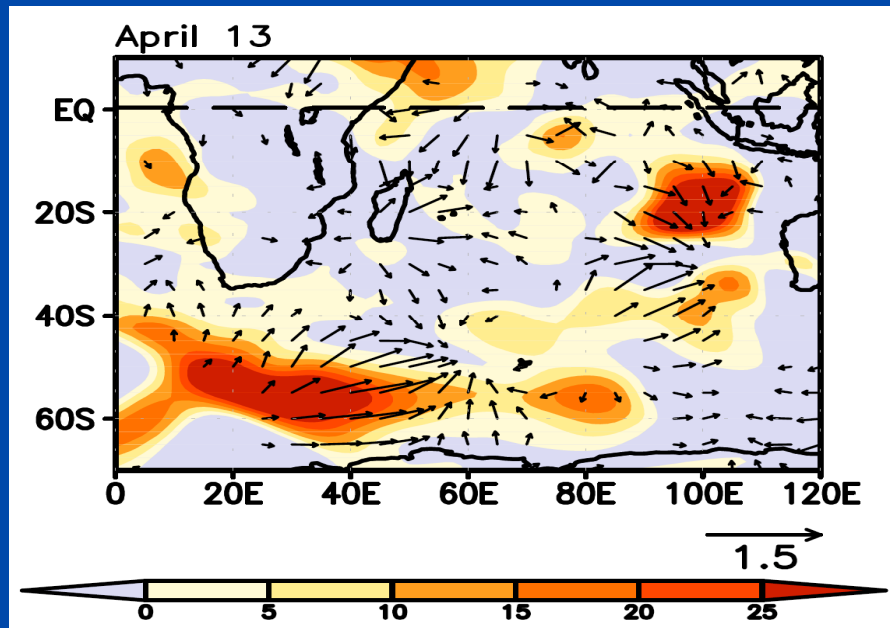
Mechanics of extratropical influences..

Upper troposphere

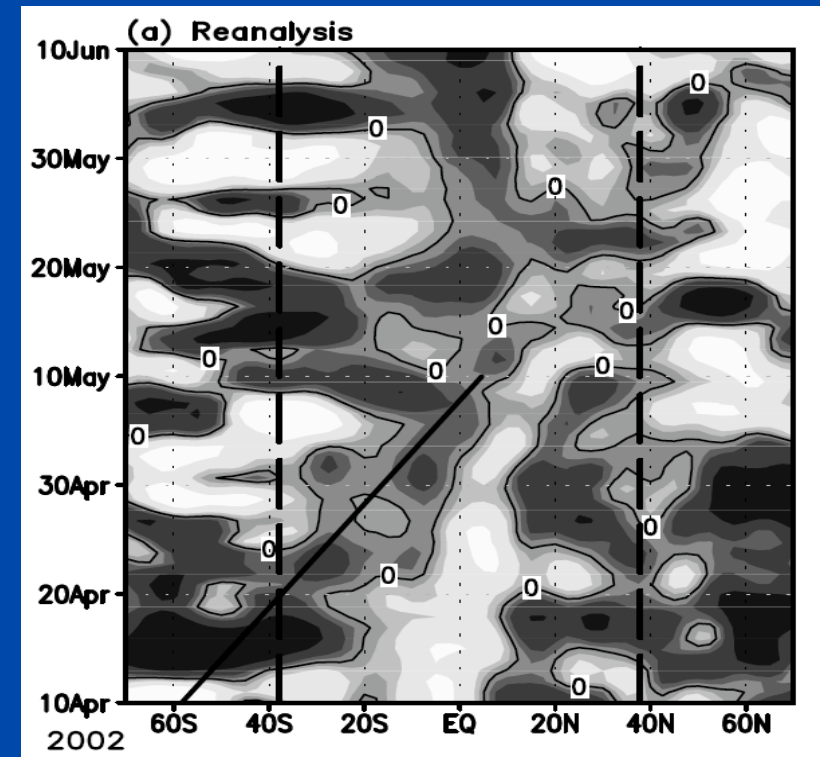
- Wave activities (W-vector, Takaya and Nakamura 1997) originate over the southern Indian Ocean where it grows by extracting kinetic energy from the mean flow.

V850

April 13



W (vector); Energy conversion (shaded)



Outline

The initiation of the MJO :

- Background and Motivations
- Model and Data
- Results

Role of the Initial Conditions and SST : No

Role of the Convection-Radiation Interactions : No

Sensitivity to the Boundary Conditions : Yes

Mechanics of the Extratropical Influences

MJO Statistics and Cases in Climate Simulations

- **Conclusions and Implications**

What we know so far...

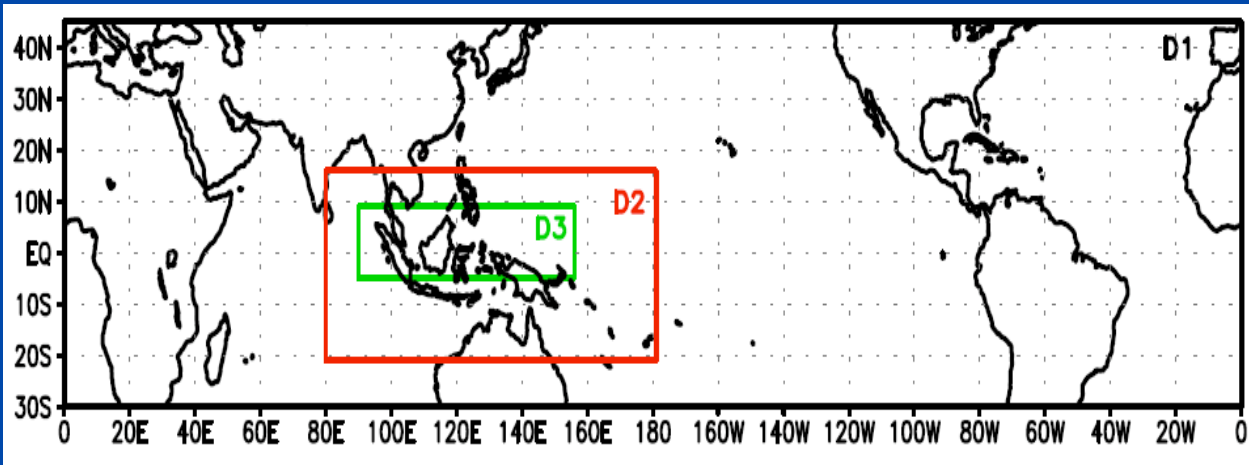
- **Extratropical influences through time-varying lateral boundary conditions are important for the chosen MJO events.**
- **Successive MJO events (with preceding events) may be influenced by the extratropics (Matthews, 2008).**

Hypotheses

1. **Multi-year simulation using a tropical channel model would reproduce the two MJO events under study.**
2. **It would also reproduce good MJO statistics if forced by time-varying boundary conditions.**
3. **MJO without extratropical influences may not be captured in a multi-year simulation.**

➤ **Use a different model with a different set up**

Model and the Simulations



**Tropical Channel WRF
or
Nested Regional Climate
Model**

Exp.	Time	Description
1DOM	1996-2000	30°S to 45°N. Covers Case 2 (Nov 2000)
1DOM_2	2000-2005	45°S to 45°N. Covers Case 1 (May 2002)

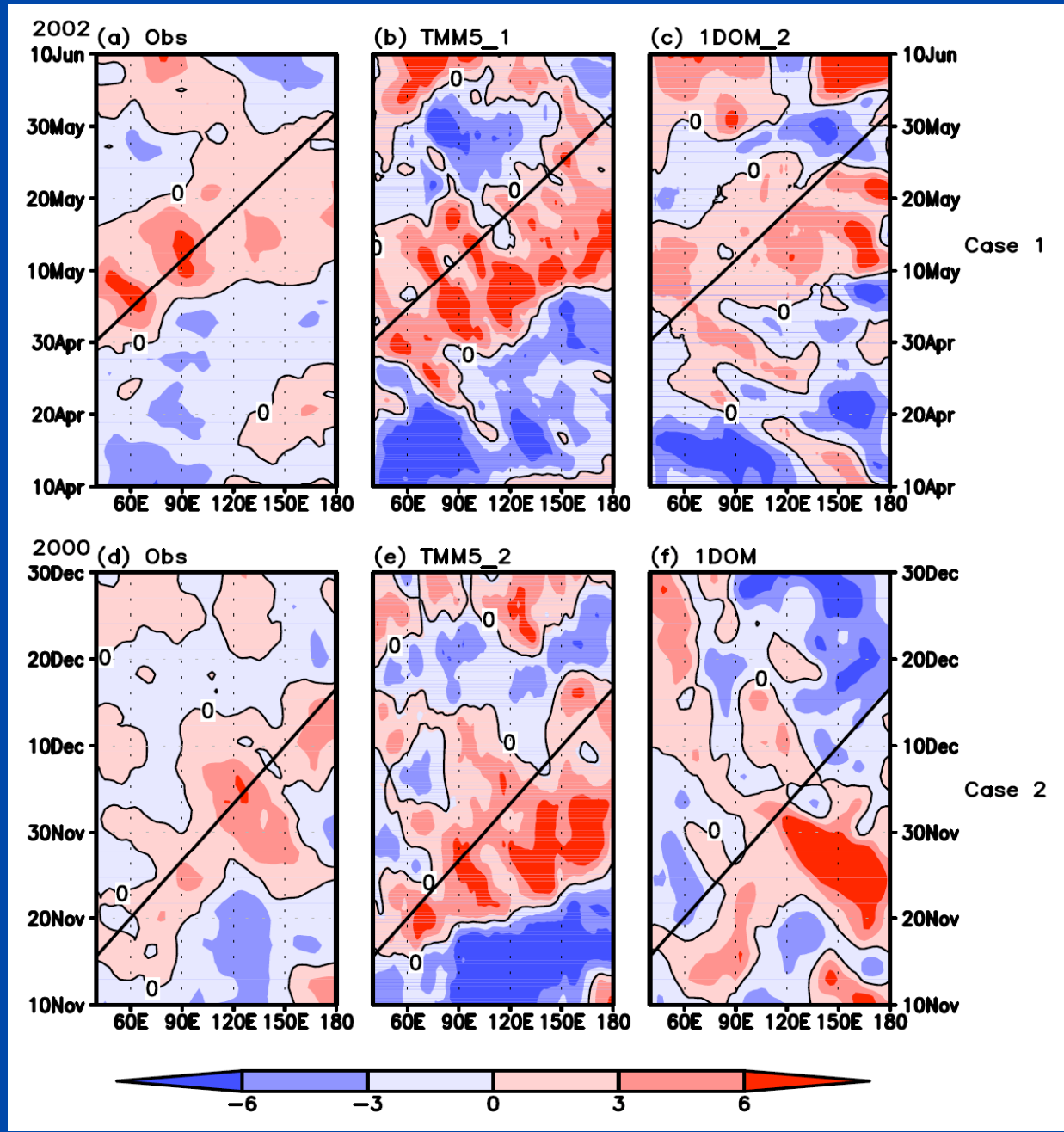
Resolution : 36/12/4 km
moisture scheme : WSM6
cumulus scheme : KF
radiation scheme : CAM

model output : 3 hr

Testing hypothesis 1: Multi-year simulation reproducing MJO event

Case 1
May 2002

Model initial time
1 Dec 1999



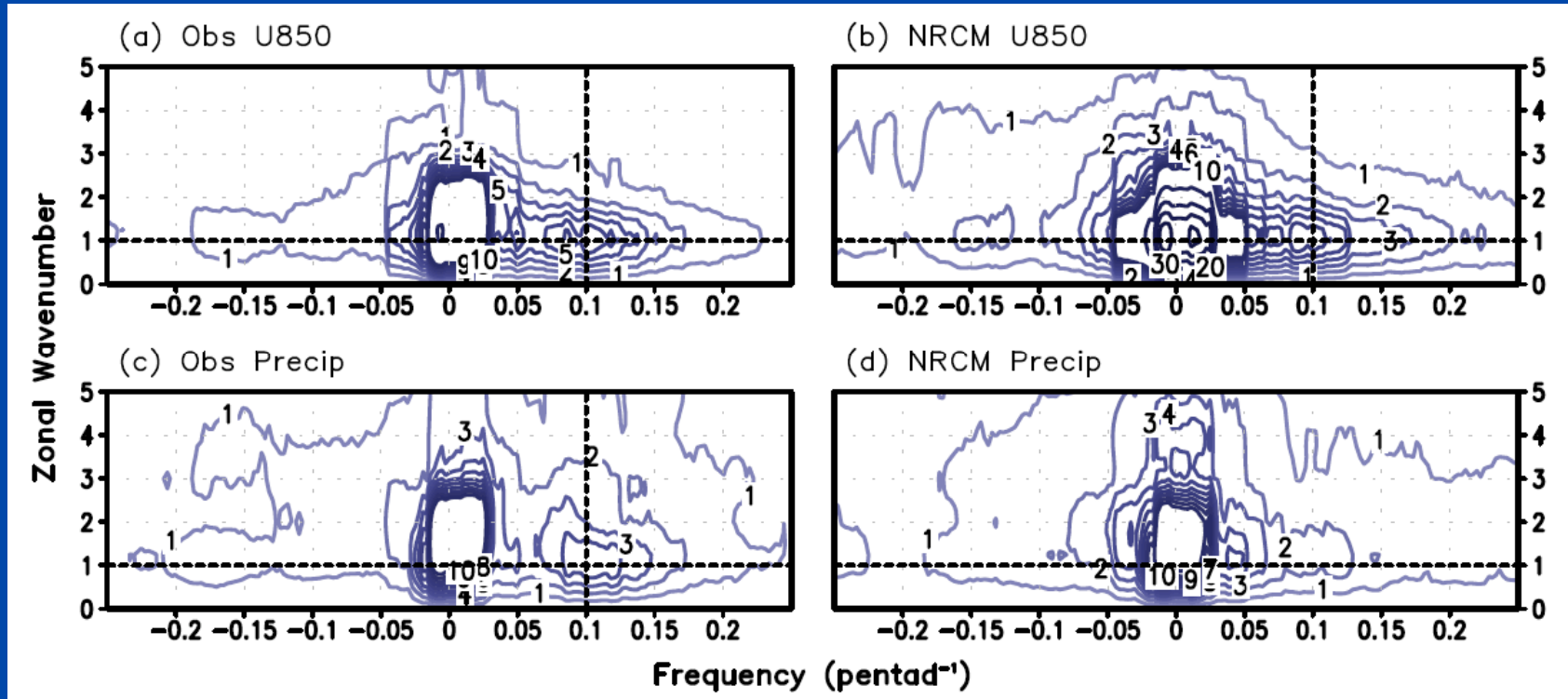
Case 2
Nov 2000

Model initial time
1 Jan 1996

Testing hypothesis 2: MJO statistics in multi-year simulation

Space-Time Spectrum (10S-10N)

K
↑



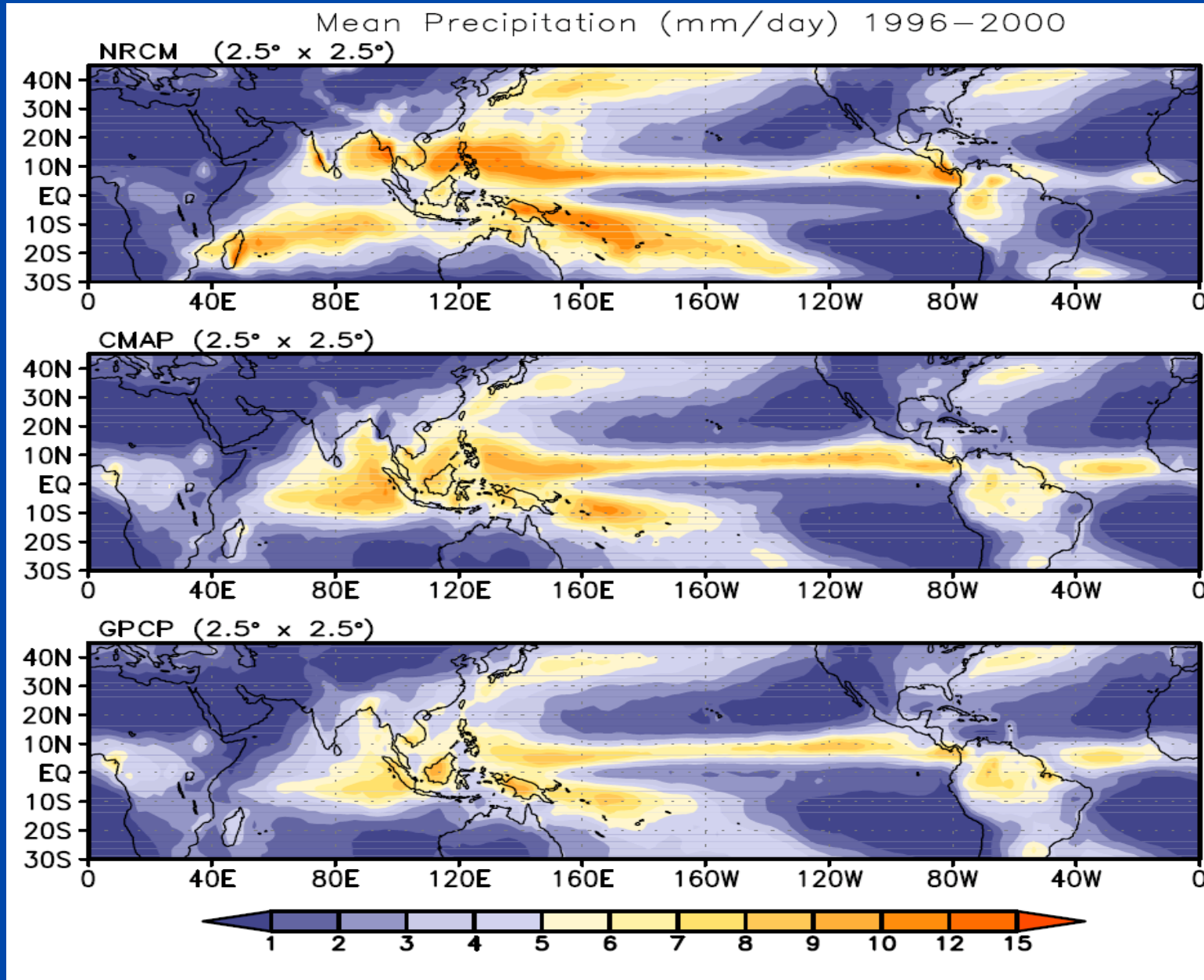
→ Frequency (per pentad)

	Obs	CAM 2RC	GFS 03C	CAM 2R	ECHAM 4	BAM 3C	BAM 3	ECHO -G	GFS 03
P	2.4	1.9	1.7	1.5	1.3	1.3	1.2	1.2	1.2

➤ MJO statistics in the NRCM not better than those in the GCMs. 22

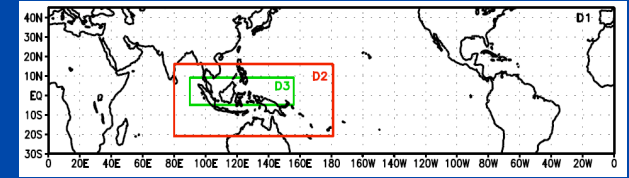
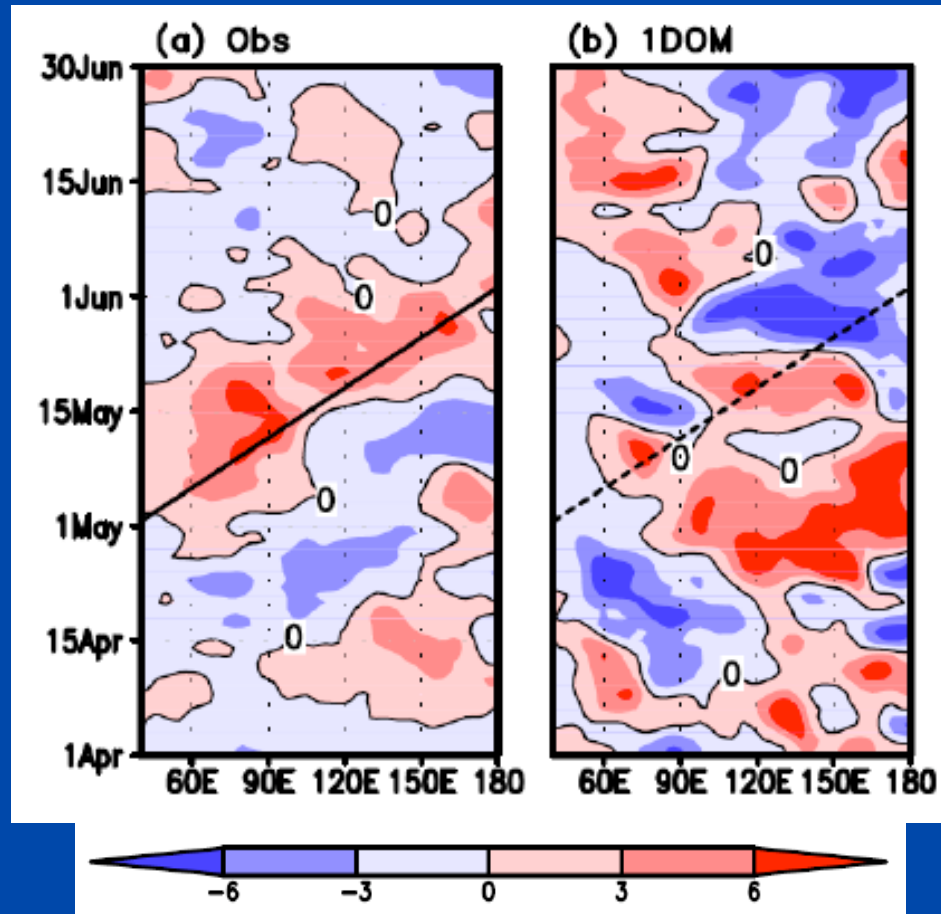
Causes behind poor MJO statistics.....

Mean Precipitation (1996-2000)



Testing hypothesis 3: MJO with no extratropical influences.....

Case 3
May
1997

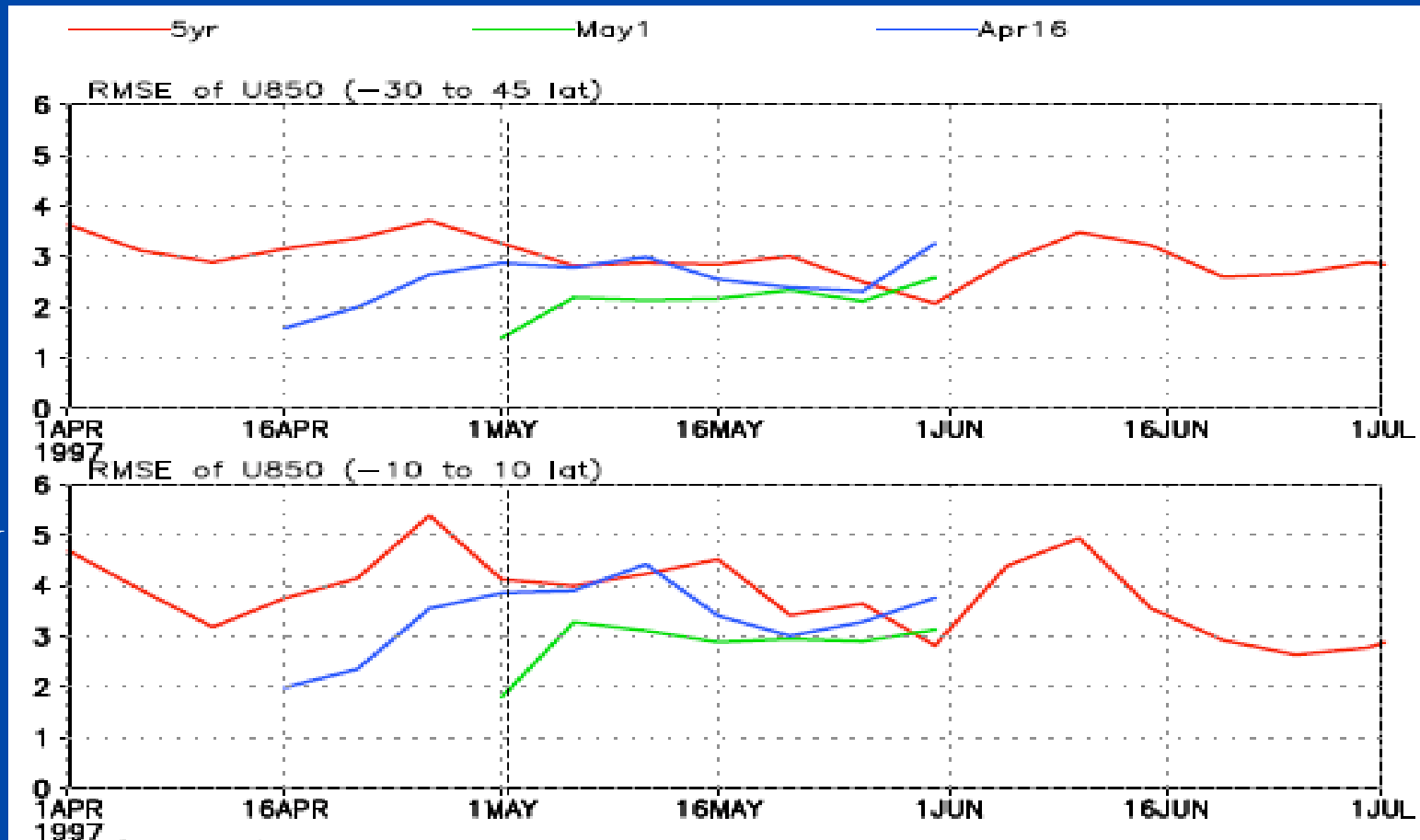


- Several sensitivity tests were conducted.
- This MJO is reproduced when the MJO signal is already present in the initial conditions.
- Does the error growth prevent this event in the model?

Error growth in the model

RMSE of U850

30S - 45N



10S - 10N

- In the absence of extratropical influence error in the mean state may prevent the MJO initiation

Implications / Outcome / Recommendation

- **An alternative view for the poor MJO simulation :**
 - **When the MJO signal starts in the dynamic field due to the lateral influences, a cumulus parameterization may work against it and weaken it.**
- **MJO prediction :**
 - **A cloud resolving domain of the tropics nested in a coarse resolution global model.**
- **MJO validation :**
 - **Model validation over the extratropics, and not concentrate in the tropics only.**
- **Necessary and sufficient conditions for the MJO initiation :**
 - **Extratropical influences in the intraseasonal time-scale may not be necessary (Gustafson and Weare 2004). Our results indicate that the lateral influences can be sufficient.**

Limitations

- **Only two MJO events were considered.**
- **Meridional extent of the model not sufficient to have a global view of the intraseasonal oscillation.**
- **.....**

Summary

- **Time-varying lateral boundary condition was the only factor found crucial for the MJO initiation which in turn comes from the extratropics.**

(Ray, Zhang, Dudhia and Chen (2009), JAS, 66, 310-331).

- **Meridional advection of zonal momentum at the lower troposphere and wave activity flux at the upper troposphere were important.**

(Ray and Zhang (2010), JAS, 67, 515-528).

- **In the absence of dynamical connection between the MJO and extratropics, the error in the mean state could be sufficient to prevent the MJO initiation.**

(Ray, Zhang, Moncrieff, Dudhia, Caron, Leung, and Bruyere (2010), Clim. Dyn., DOI: 10.1007/s00382-010-0859-2).

- **The MJO structures in a high-resolution nested regional climate model was explored.**

(Ray, Zhang, Moncrieff, and Dudhia (2010), Clim. Dyn. In preparation).

THANK YOU

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Rests are
Supplementary slides

Causes behind poor MJO statistics.....

Define an MJO index...

Method

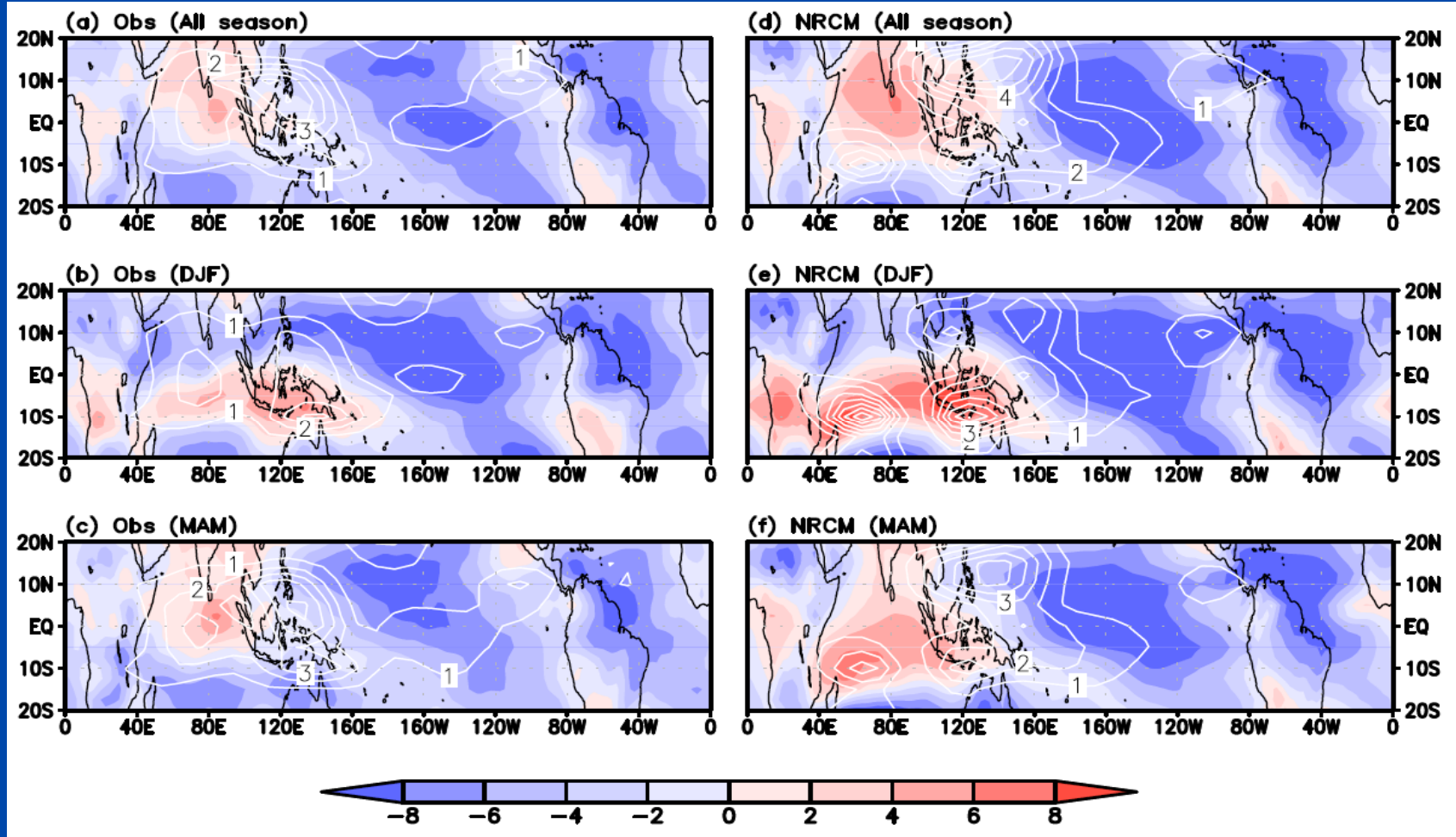
MJO Variance (MV)

- 20-90 day and $k = 1-5$ filtering.
- SVD analysis on filtered U850 and Precipitation.
- Separate the leading SVD modes based on North et al. criteria.
- Use these leading modes to reconstruct the time series of U850 and Precipitation.
- We call these MJO U850 (U850*) ; and MJO Precip (P*).
- Variance of these two quantities are referred as the MJO variance.

Causes behind poor MJO simulation.... MJO and mean state

Obs MJO variance (contoured), U850 (shaded) Model

All



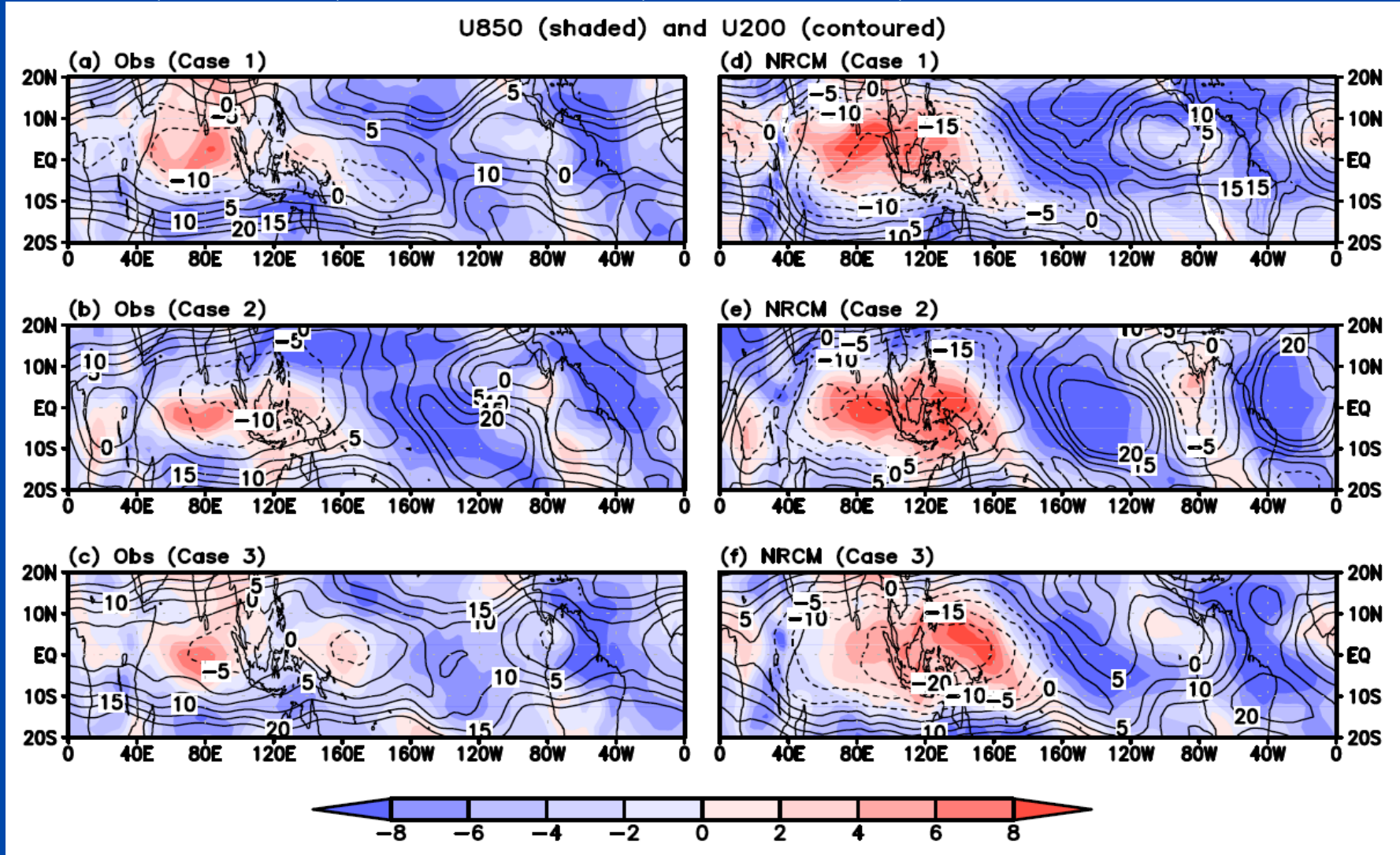
DJF

MAM

- Error in the mean state responsible for the poor MJO statistics.
- What happens for an MJO event with no extratropical influence?

Testing hypothesis 3: MJO with no extratropical influences.....

U850 (shaded) and U200 (contoured)



Case 1
May 2002

Case 2
Nov 2000

Case 3
May 1997

• Is the forecast error comparable to the climate error ??

Mechanics of extratropical influences

- **Upper troposphere: Wave Activity Flux (W-vector, Takaya and Nakamura 1997)**

$$W = \frac{1}{2|U|} \begin{bmatrix} u(\psi_x^2 - \psi\psi_{xx}) + v(\psi_x\psi_y - \psi\psi_{xy}) \\ u(\psi_x\psi_y - \psi\psi_{xy}) + v(\psi_y^2 - \psi\psi_{yy}) \end{bmatrix}$$

- **Source of energy (Simmons et al. 1983)**

$$C = \underbrace{-\overline{(u'^2 - v'^2)}}_1 \frac{\partial \bar{u}}{\partial x} - \underbrace{\overline{u'v'}}_2 \frac{\partial \bar{u}}{\partial y}$$

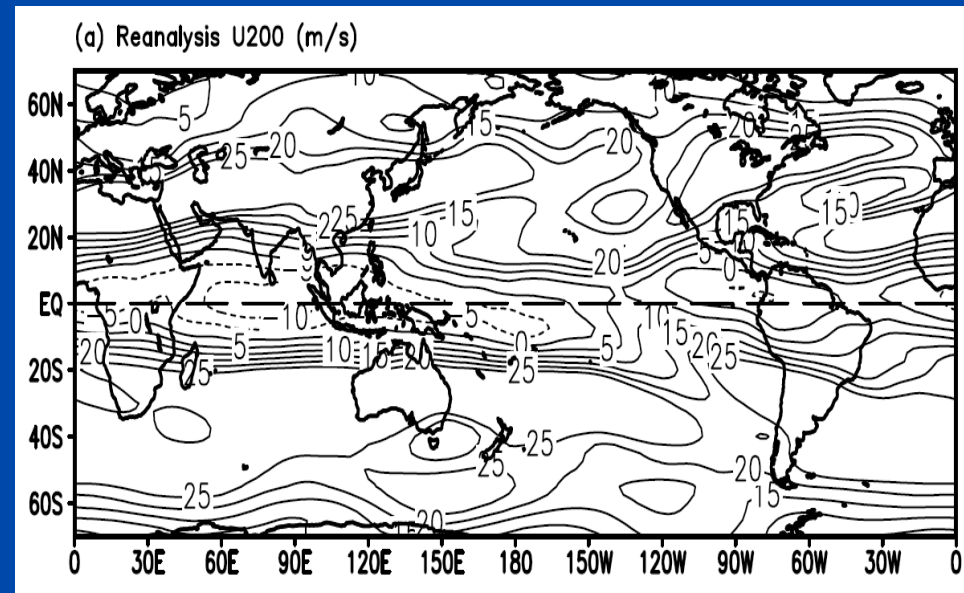
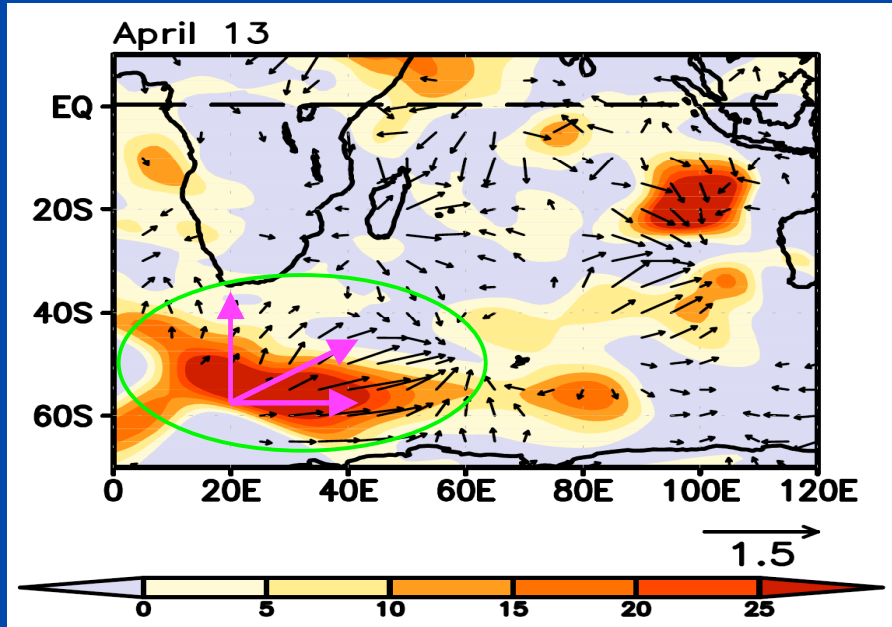
1 : contribution from anisotropy

2 : contribution from zonal momentum

C = Conversion of kinetic energy from the mean flow to a disturbance

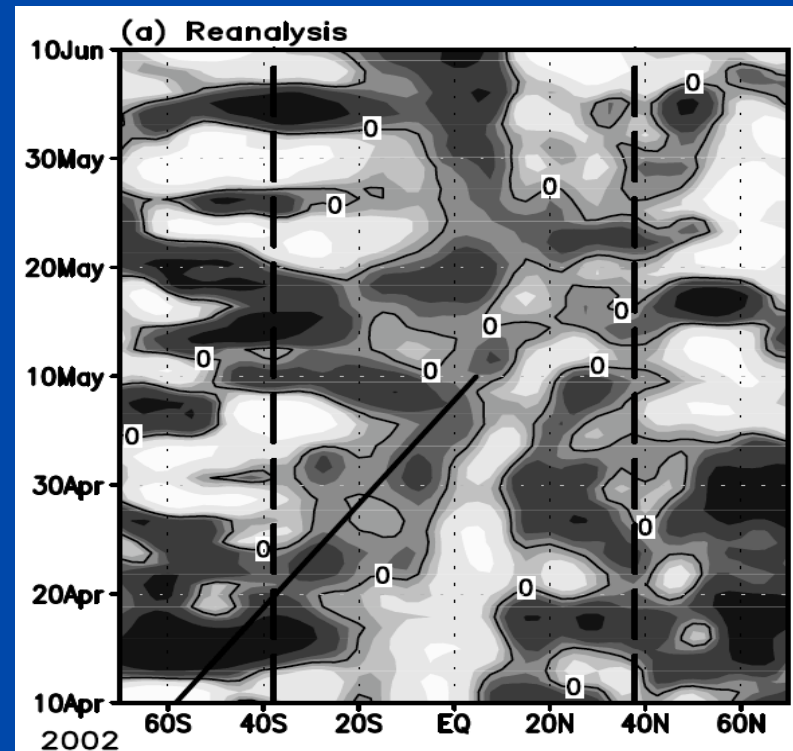
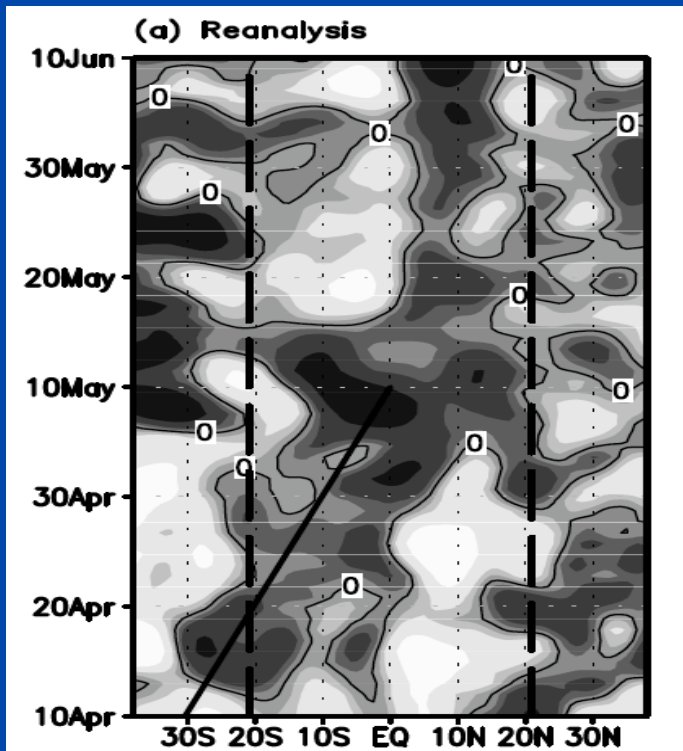
April 13

Wave Activity Flux and its energy source



U200

U850

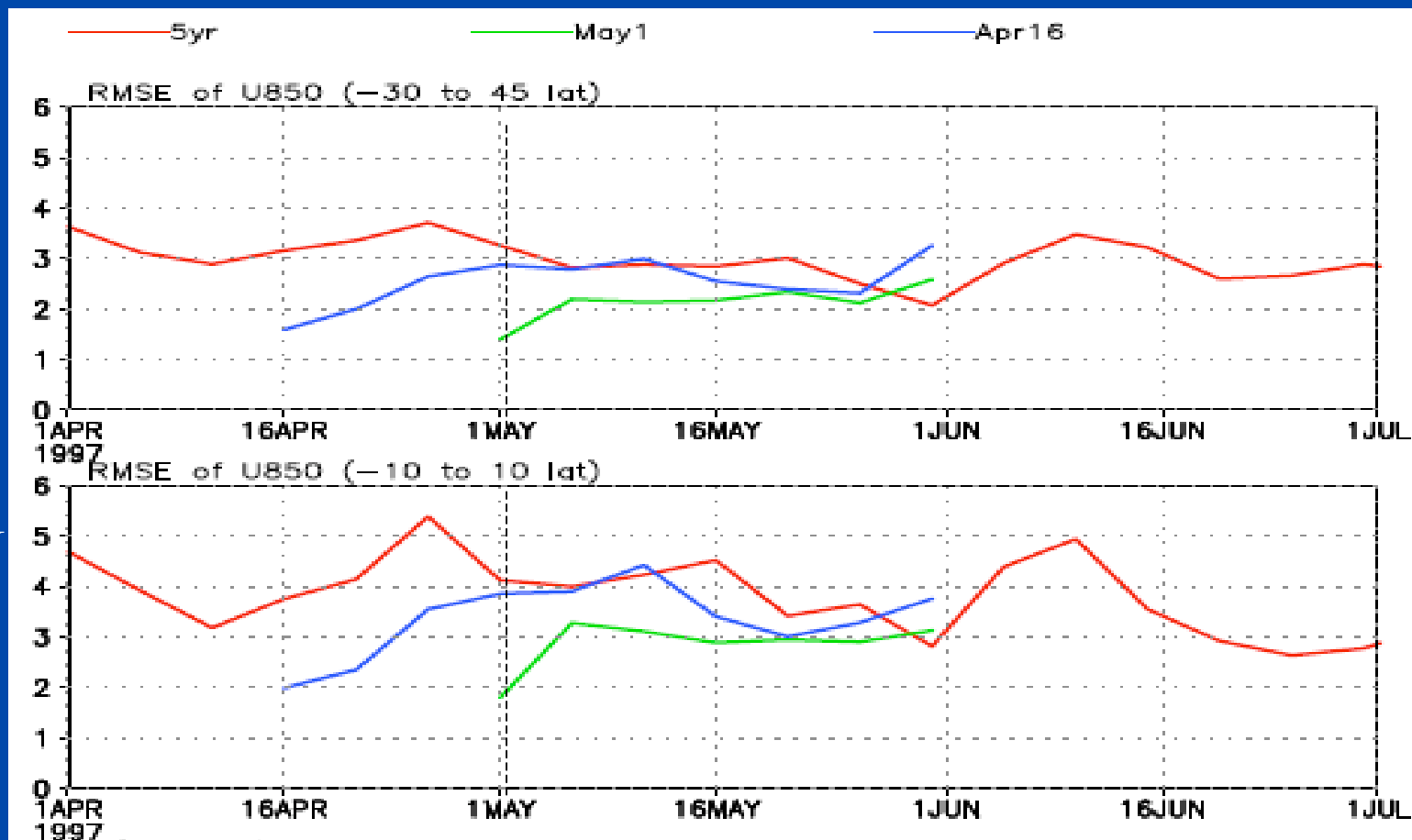


V850

Is the forecast error comparable to the climate error ??

RMSE of U850

30S - 45N



10S - 10N

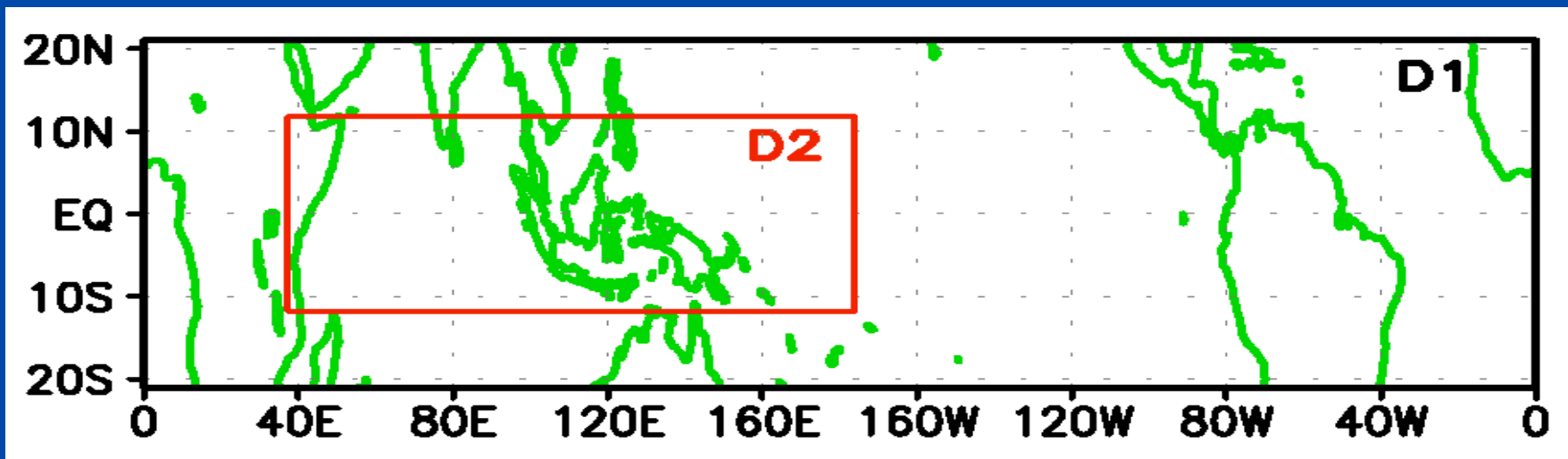
• Consistent with Boyle et al. (2008)

- In absence of extratropical influence error in the mean state prevents the MJO initiation

Simulations using TMM5

Experiment	Integration Time	Remarks
D1	1 Mar – 30 June	One domain. Varying SST.
D1+D2	1 Mar - 30 June	2 way nested, 111/37 km. Varying SST.
CS1	10 Apr – 10 June	Control simulation. Constant SST. Lateral boundaries at 21SN.
.....
.....

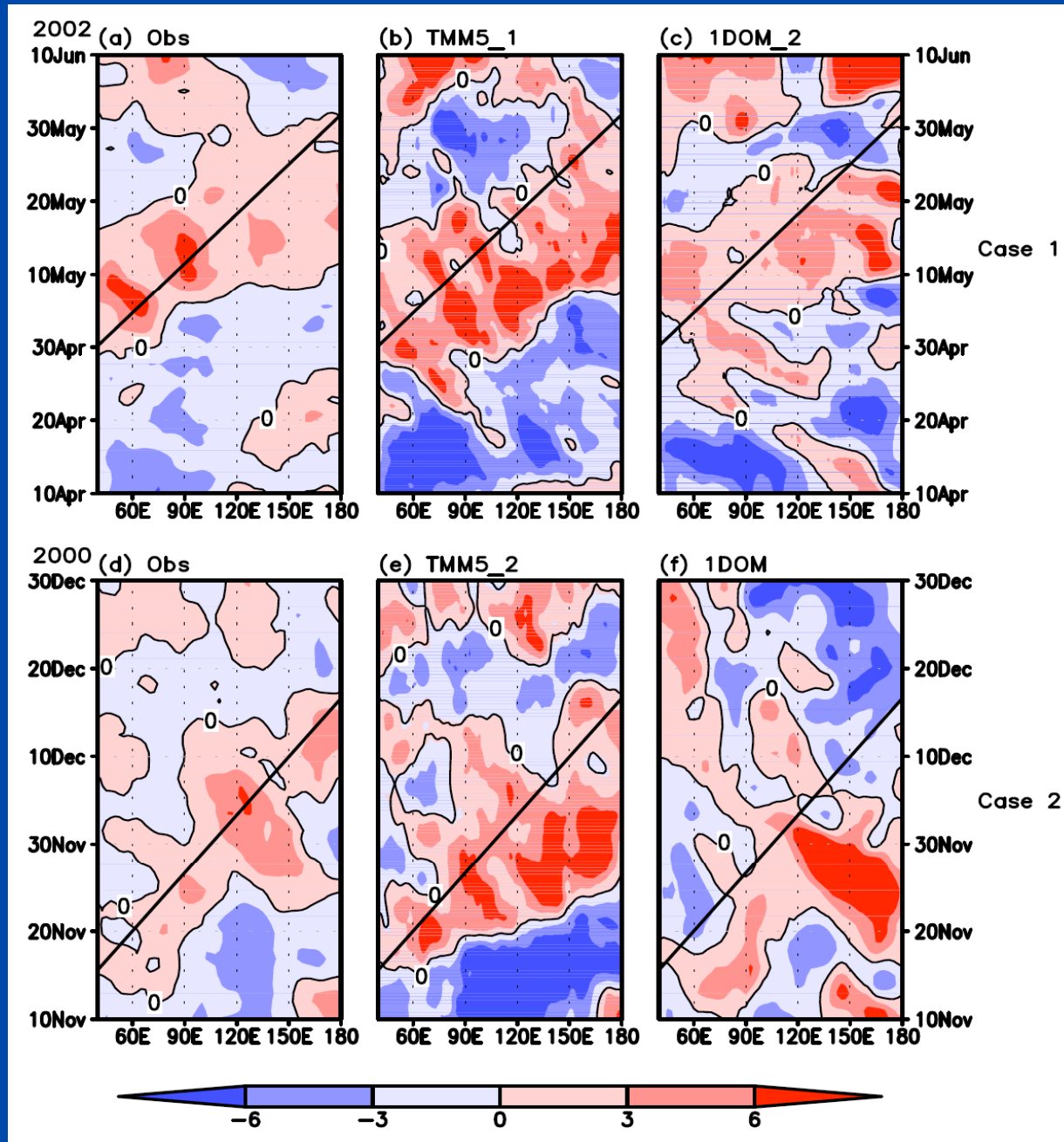
➤ More than 20 sensitivity experiments for Case 1



Testing hypothesis 1: Multi-year simulation reproducing MJO event

Case 1
May 2002

Model initial time
1 Dec 1999



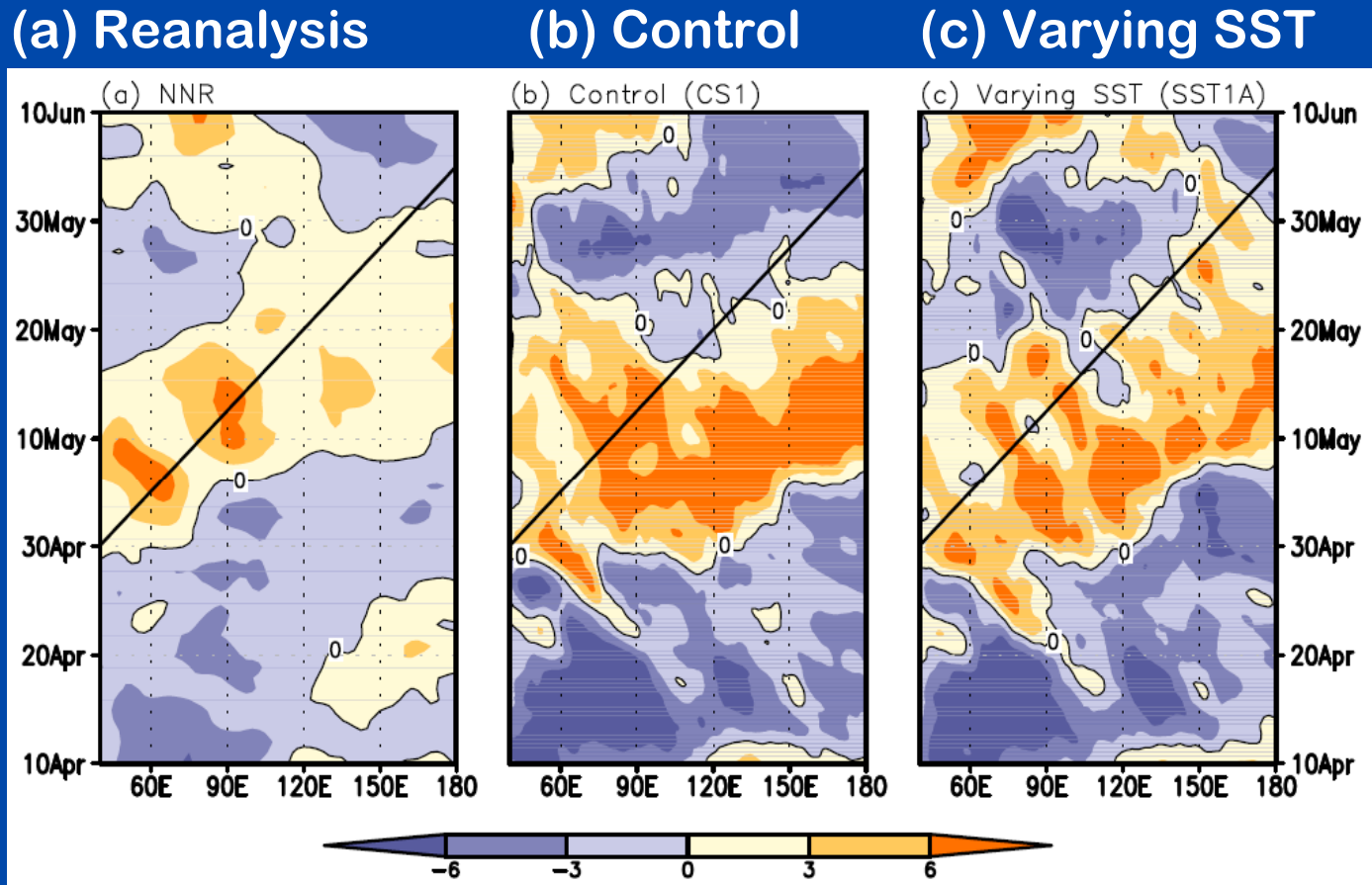
Case 1

Case 2

Model initial time
1 Jan 1996

Role of the SST (Case 1: May 2002)

U850

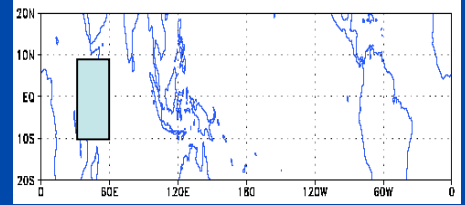
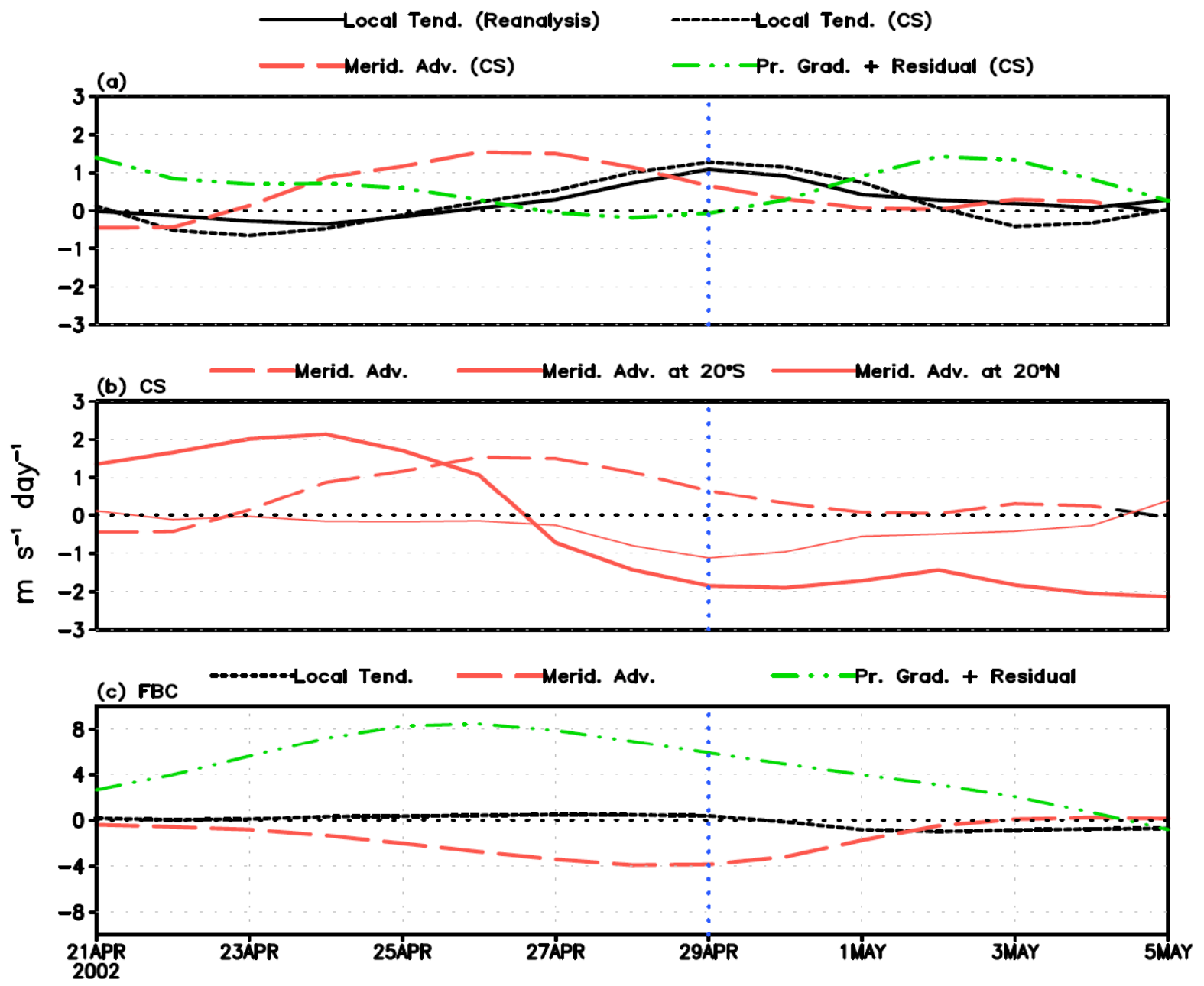


- Intraseasonally varying SST is not a determining factor.
- Stochastic Forcing with time-scale < 6 hr from lateral boundaries do not play any role.
- Consistent for Case 2 (Nov-Dec 2000) when the SST was 1° C cooler than that for Case 1.

Sensitivity to the Initial Conditions

- **Case 1: Total 12 tests were conducted, using constant and varying SSTs. (t = -5 day to t = 5 day)**
 - **Same for Case 2.**
- **Model Initial Condition is not a determining factor.**

Zonal Momentum Budget (10S-10N, 40E-50E)



- Meridional advection of zonal momentum is crucial at the lower troposphere.

- What happens at the upper troposphere?