Convective Momentum Transport Associated with the Madden-Julian Oscillation

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Acknowledgments: NSF/Climate & Large-scale Dynamics

Convective Momentum Transport

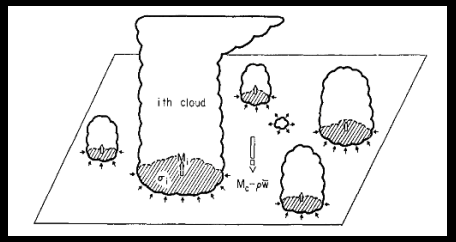
; The transfer of momentum from the convective to synoptic and planetary scales

- **Momentum equation**

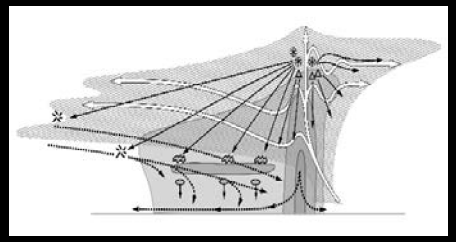
$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial v}{\partial y} - \omega\frac{\partial u}{\partial p} - \frac{\partial \phi}{\partial x} + fv + X$$

Momentum transport

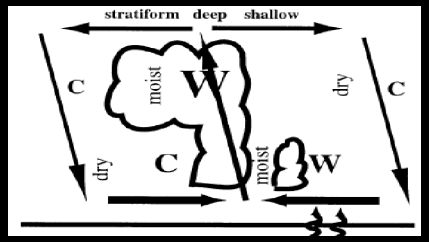
Cloud → MCS → CCEWs → **MJO**



Arakawa & Shubert (1974)



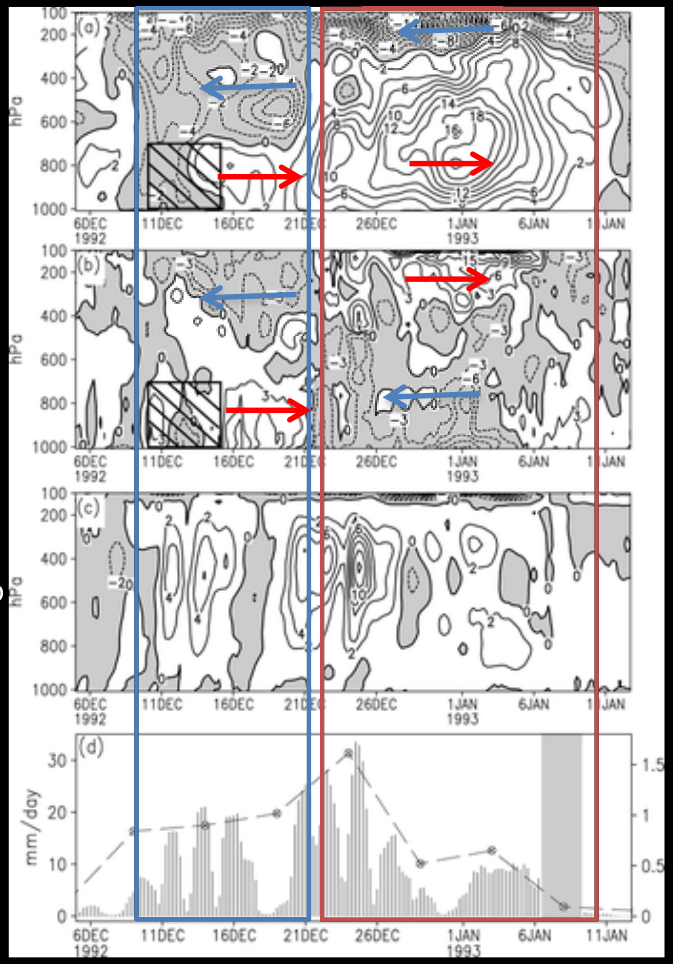
Cetrone and Houze (2011)



Straub & Kiladis (2003)

GCM: Unresolved — Part-unresolved, part-resolved — Resolved

CMT: Roles for the MJO in observation



MJO1: late Dec-early Jan

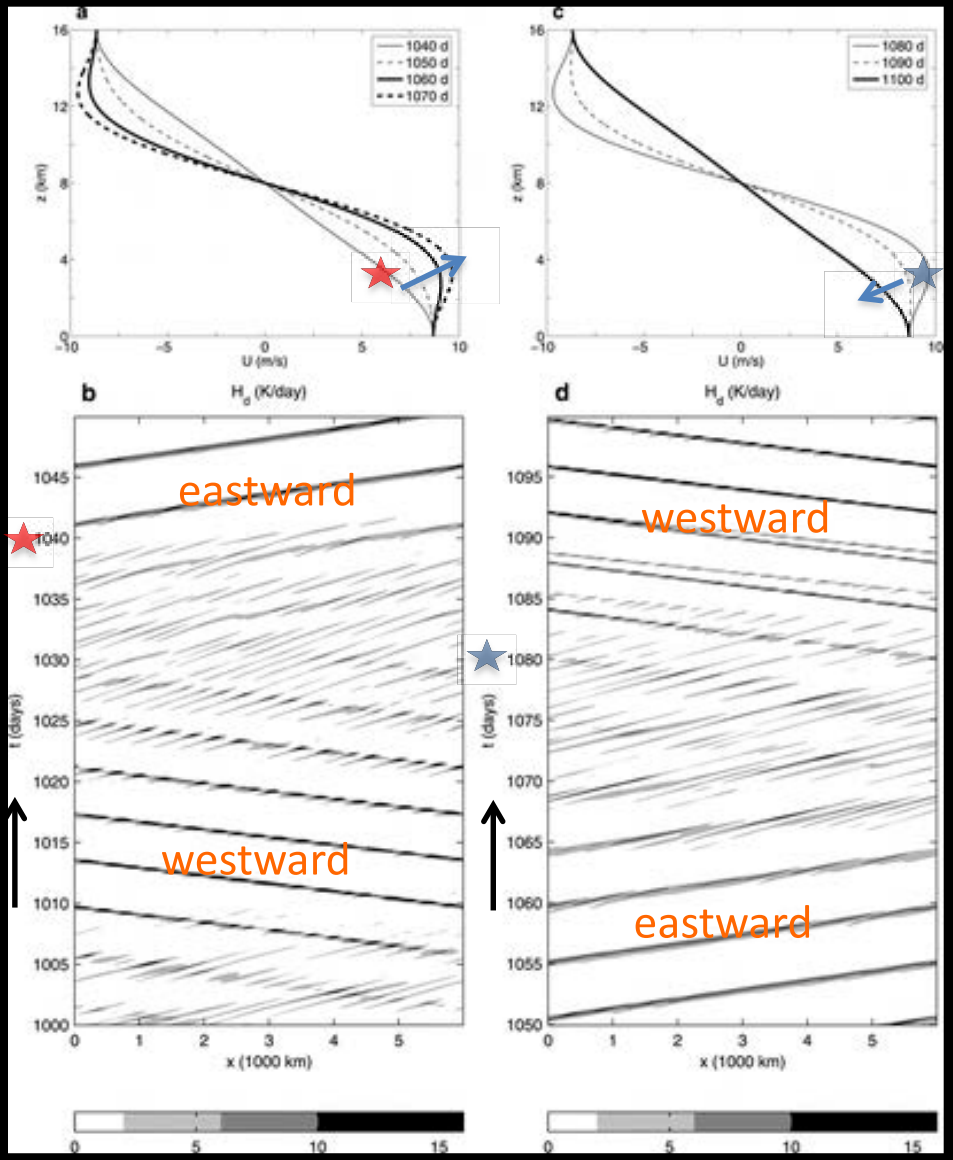
***Tung and Yanai (2002a,b)* - TOGA-COARE**

- ✓ Define CMT as the residual of momentum budget using 6-hourly objective analysis with 2.5° x2.5° spatial resolution, 43 vertical levels.
- ✓ *CMT* and local time change of u have the same order of magnitude of 3-6 m/sec/day.
- ✓ **Westerly onset**: Upscale CMT (help large scale maintain vertical shear)
- ✓ **WWB**: Downscale CMT (decelerate the large scale-flow and reduce wind shear by vertical mixing of momentum)

An Idealized Dynamical Model with CMT

U_{MJO}

CCW



Majda and Stechmann (2009)

Two-way interaction between the MJO and synoptic-scale CCWs

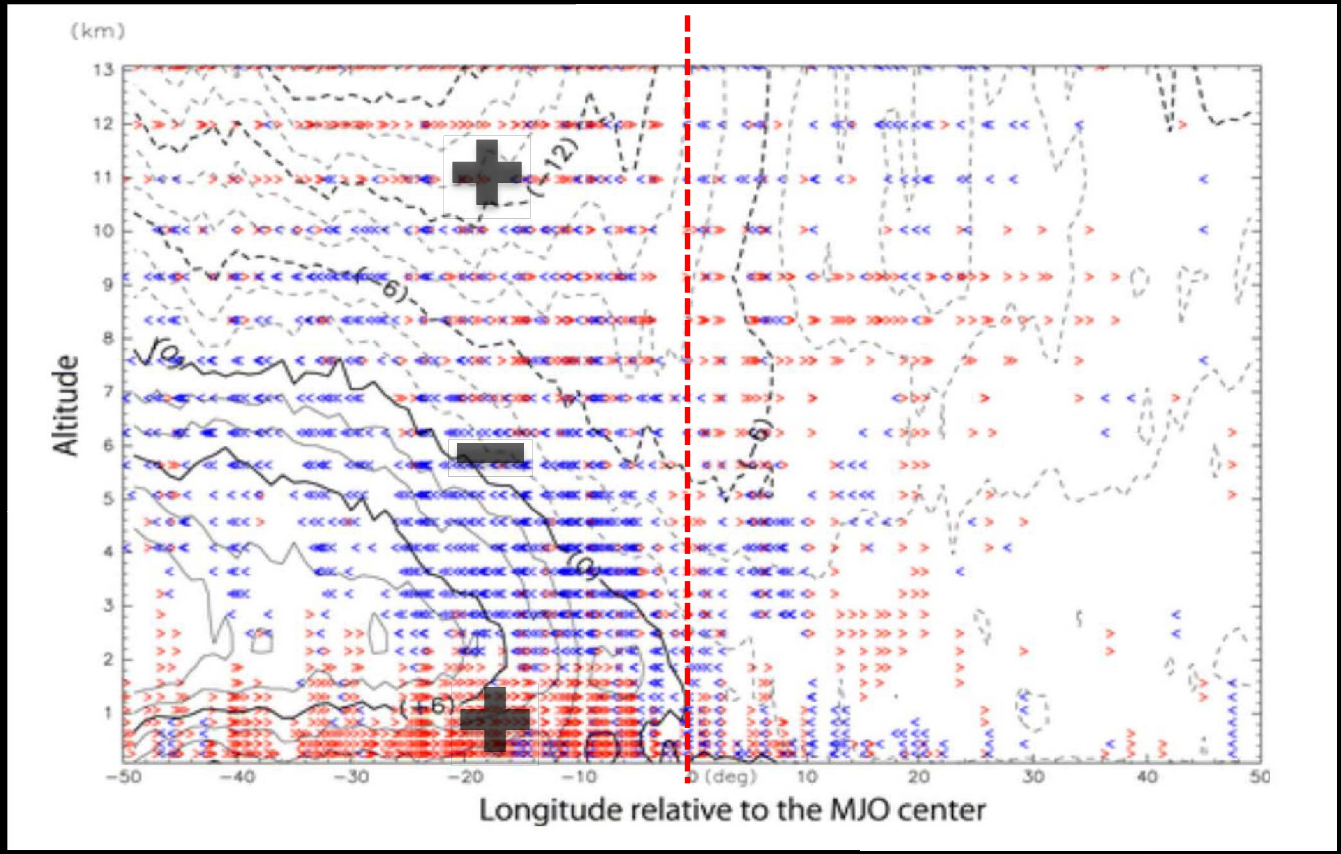
$$\frac{\partial \bar{U}}{\partial T} + \frac{\partial}{\partial z}\overline{\langle w'u' \rangle} = 0$$

$$\frac{\partial u'}{\partial t} + \bar{U}\frac{\partial u'}{\partial x} + w'\frac{\partial \bar{U}}{\partial z} + \frac{\partial p'}{\partial x} = S'_{u,1}$$

Cloud Resolving Model: NICAM (7 km)

Miyakawa et al (2012)

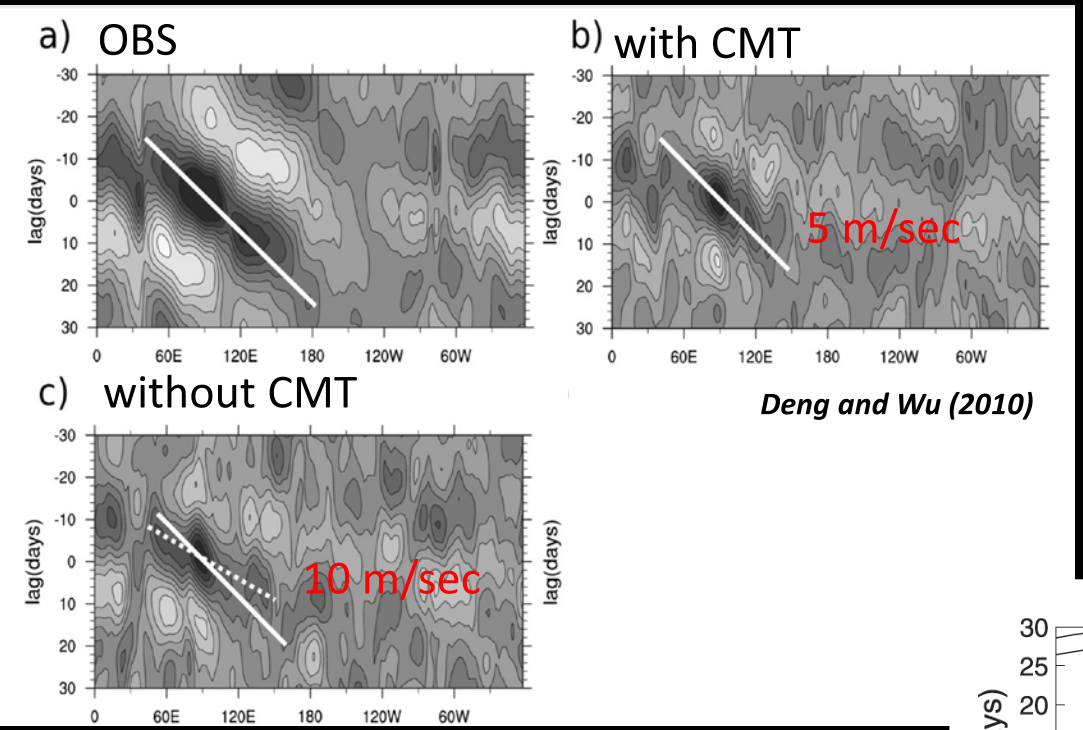
Composited MJO CMT by MCS based on 32 days simulation (western Pacific)



Role of CMT for the MJO:

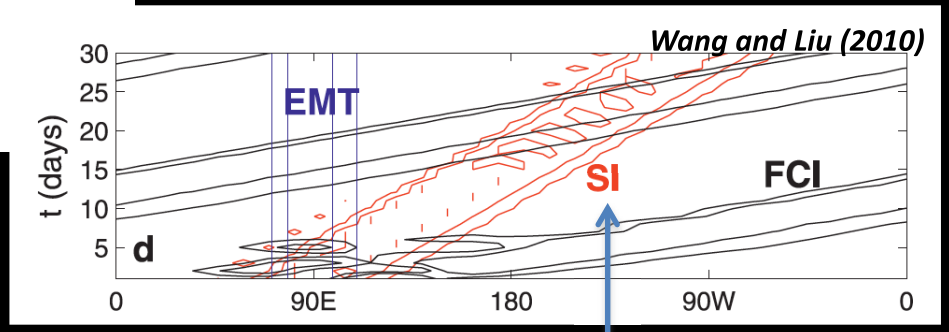
- **Slow down: more realistic MJO eastward propagating speed**

GCM: ISUCCM3



Deng and Wu (2010)

Idealized model: 2 and 1/2 model



Part 1

- Characterize 3D CMT structure associated with the MJO
- Evaluate relative contributions from different temporal/spatial scale systems

	Period	Resolution	Parameterized CMT output
CFS Reanalysis	1998-2010 (+ 10 yrs) NDJFMA	0.5 degree 6-hourly	Yes

Submitted to J. Climate

Method using CFSR

- **Momentum equation in model grid**

$$\frac{\partial \bar{u}}{\partial t} = -\frac{\partial \overline{uu}}{\partial x} - \frac{\partial \overline{uv}}{\partial y} - \frac{\partial \overline{u\omega}}{\partial p} - \frac{\partial \overline{u'u'}}{\partial x} - \frac{\partial \overline{u'v'}}{\partial y} - \frac{\partial \overline{u'\omega'}}{\partial p} - \frac{\partial \bar{\phi}}{\partial x} + f\bar{v} + \bar{F}_x$$

CMT due to **large scale**

CMT due to **meso-scale**

1. Resolved scale
2. Unresolved scale

CMT parameterization

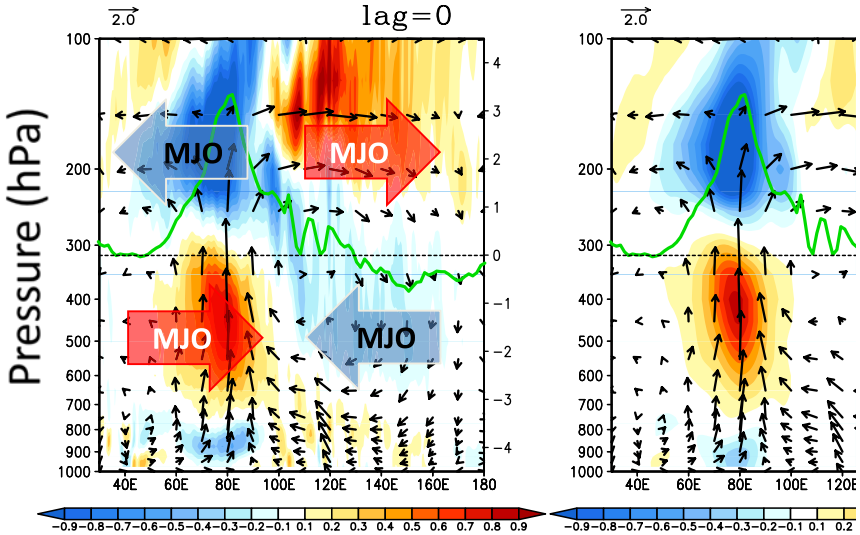
5° - **spatial scale separation**

Miyakawa et al (2012)

Vertical structure of the **grid scale** CMT associated with the MJO (IO)

Regressed CMT (shaded) onto the MJO index: (5S-5N averaged)

$\partial\bar{u}\bar{\omega}/\partial p$ [Meso-scale $(-\partial u'\omega'/\partial p)$]



Easterly acceleration Westerly acceleration
(m/sec/day)

MJO rain

(mm/day)

multiplied by 4

✓ Same vertical structure in sign & in agreement with MJO wind direction

Cannot be fully resolved due to model resolution

Temporal scale separation for large scale u-transport

Temporal filtering with different cut-off frequencies

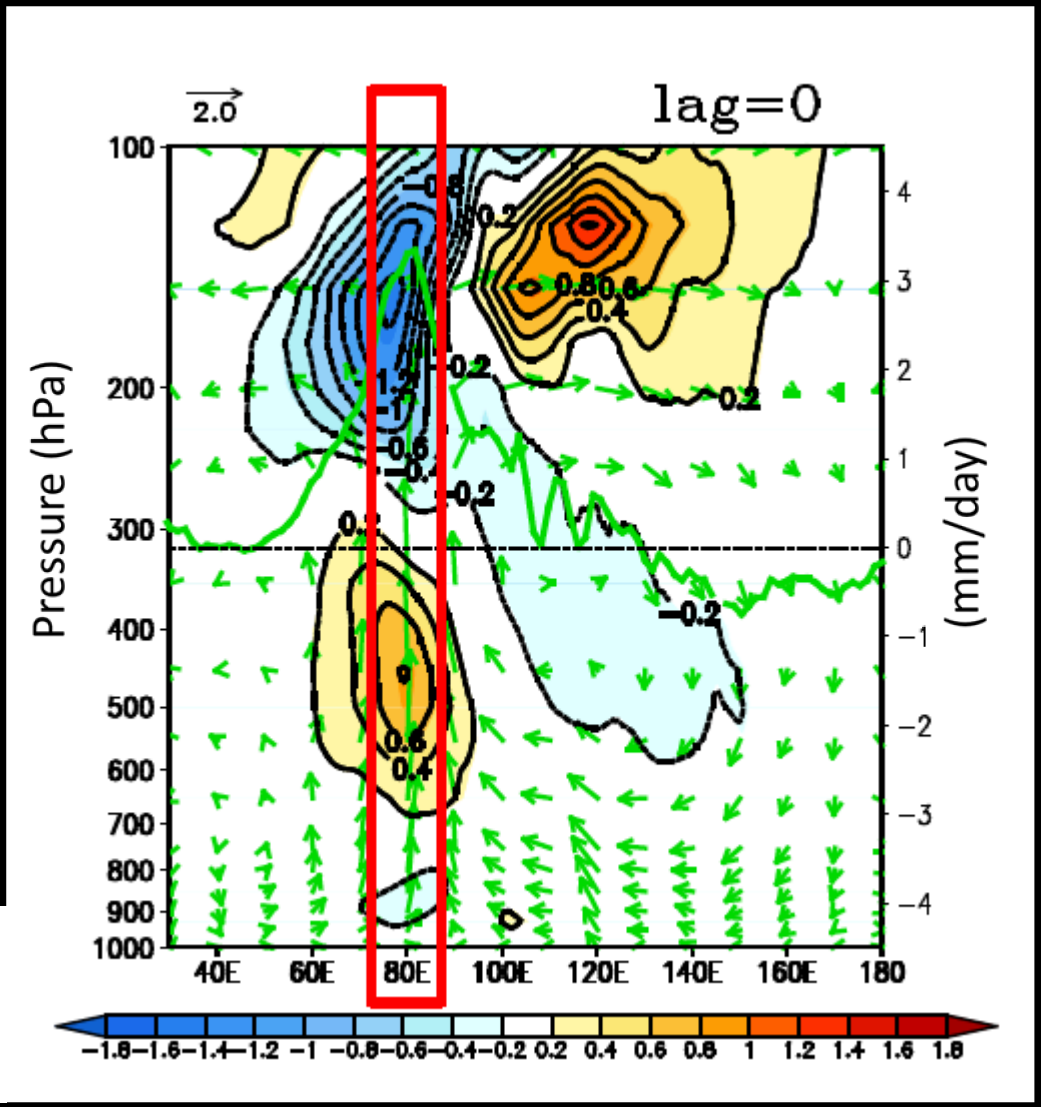
$$-\frac{\partial[u][\omega]}{\partial p}$$

[u]

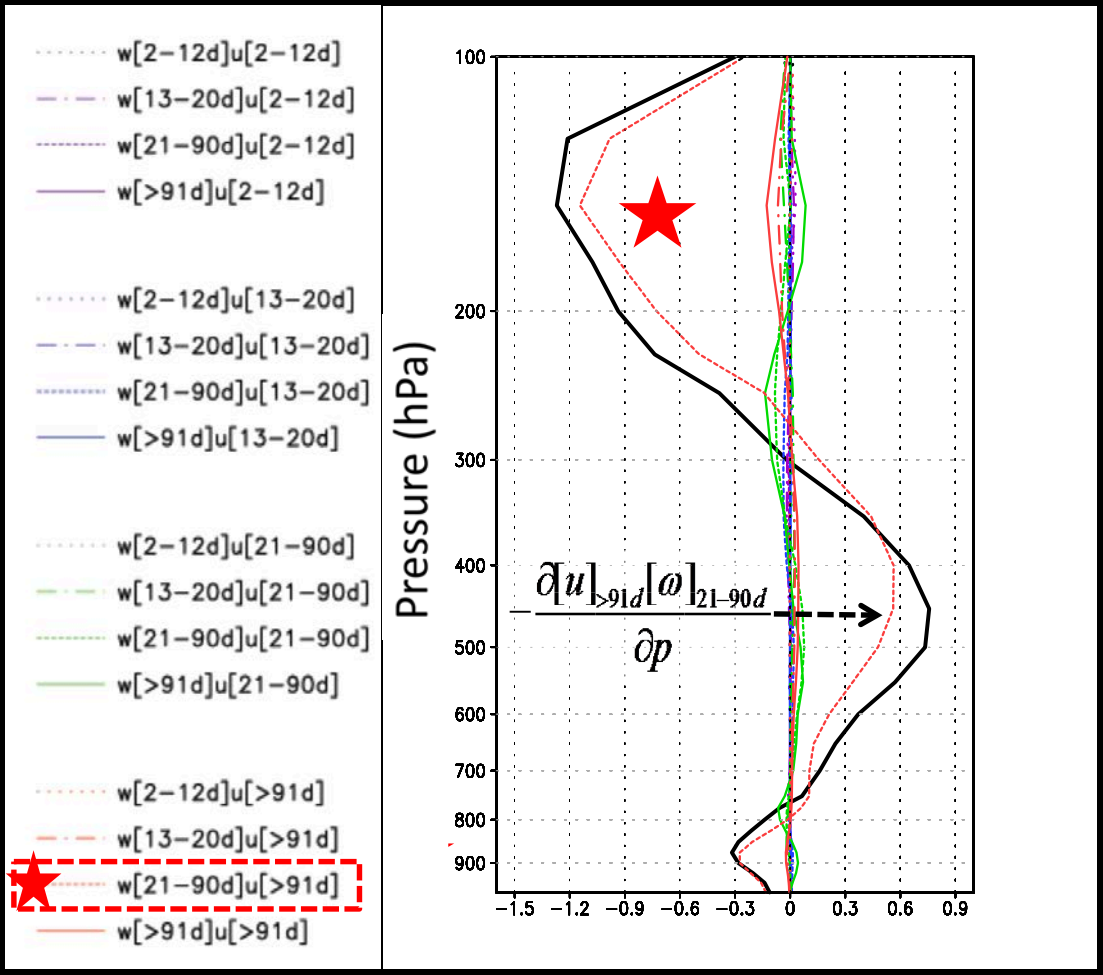
[w] Time filter	2-12	13-20	21-90	91-
2-12	1	5	9	13
13-20	2	6	10	14
21-90	3	7	11	15
91-	4	8	12	16

[ ] : 5°-radius circular average

Shaded: regressed $\partial[u][w]/\partial p$
contour: $\sum_1^{16} nth\ term$



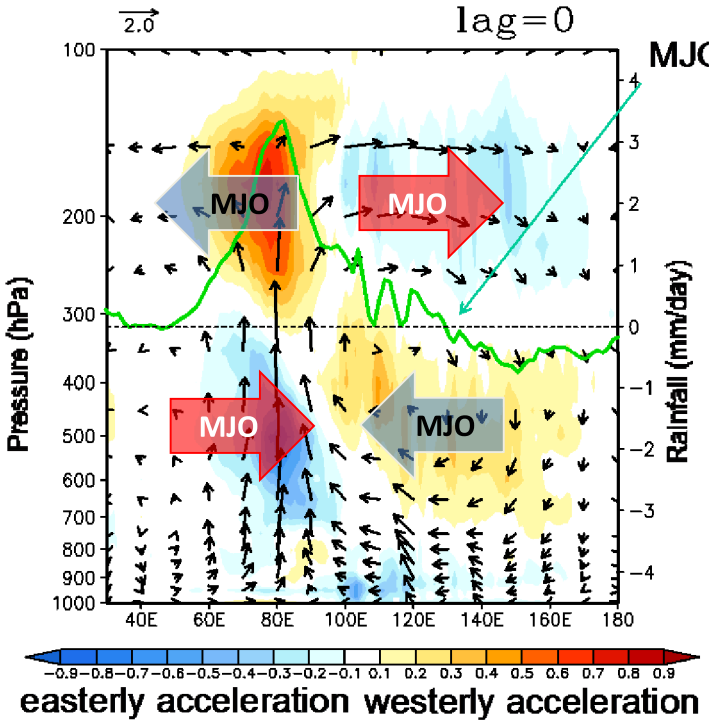
Temporal scale separation for large scale u-transport



The total grid-scale tendency is mainly contributed by the transport of *seasonal mean u-wind* [> 91 days] by *the MJO-scale vertical motion* [21 days < u < 90 days]

Vertical structure of the **subgrid (=parameterized)** CMT associated with the MJO (IO)

Regressed CMT (shaded) onto the MJO index (5S-5N averaged)

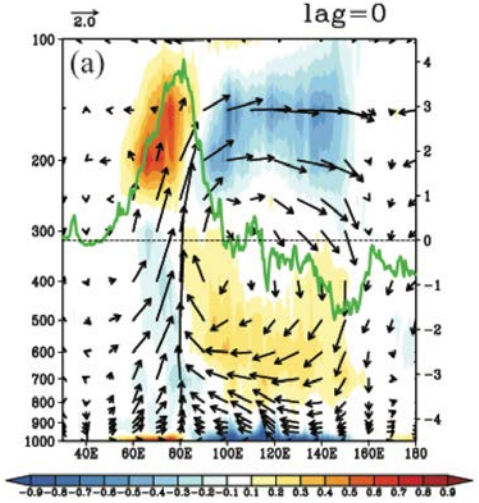


✓ **Three layer vertical structure of the CMT: *interfere with the establishment of the MJO circulation (except for PBL)***

* The structure is consistent with the result based on cloud resolving model by Miyakawa et al. 2012

[Meso-scale ($-\partial u'\omega'/\partial p$)]

Subgrid CMT (ECMWF YOTC)

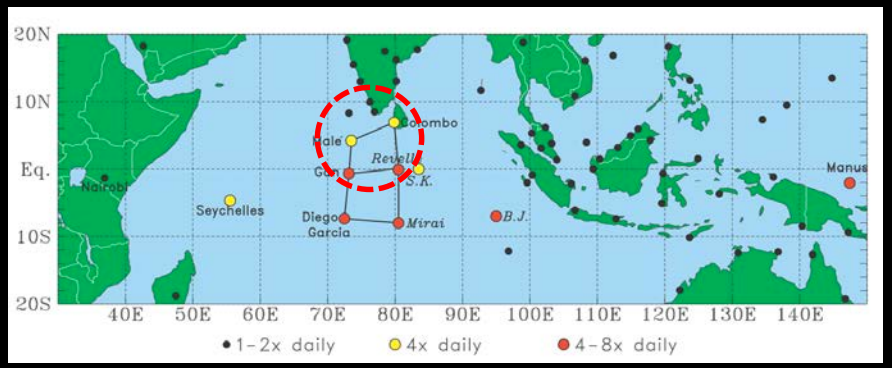


Part 2

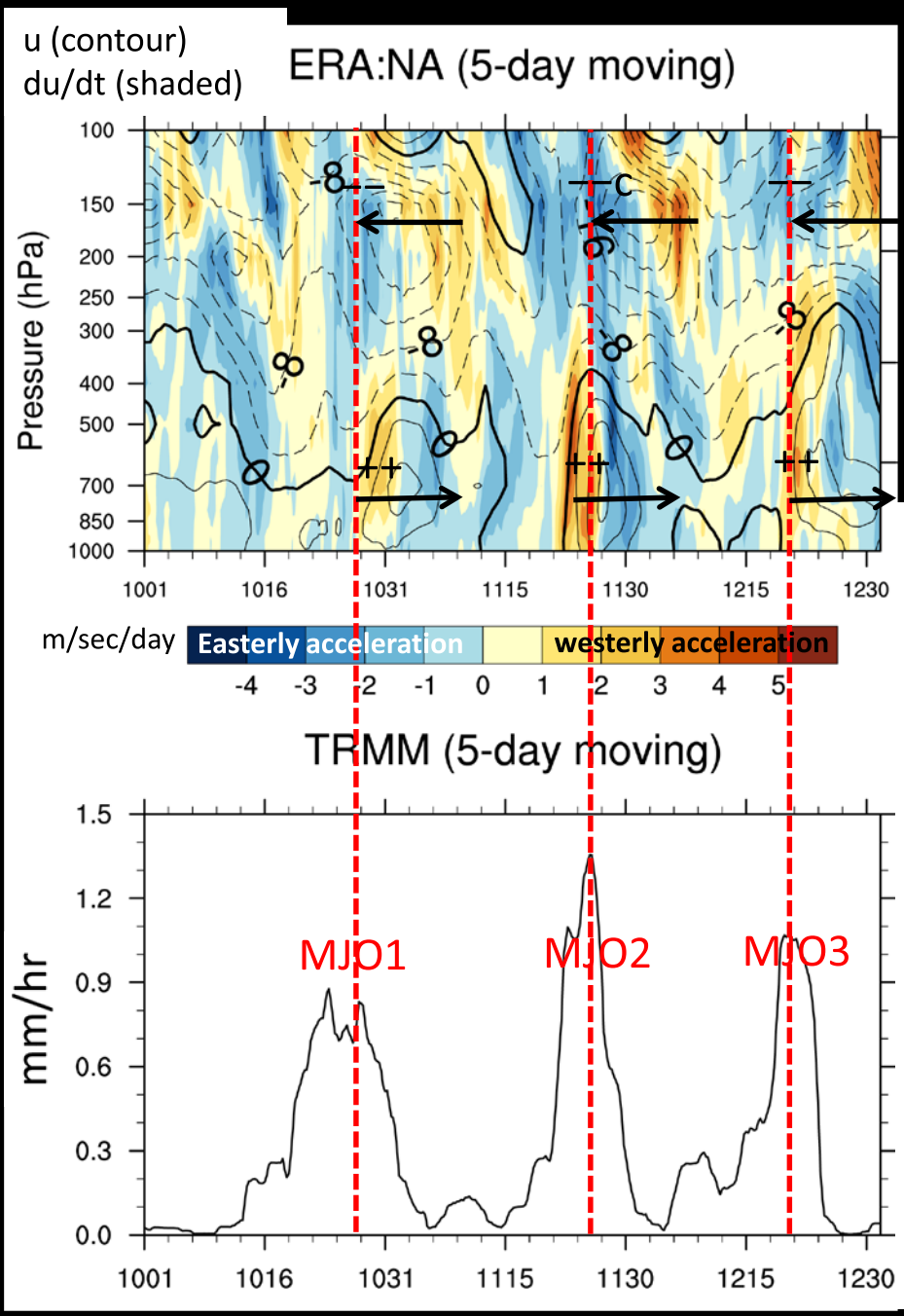
- Momentum budget analysis associated with the westerly wind event of MJOs during DYNAMO

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial v}{\partial y} - \omega\frac{\partial u}{\partial p} - \frac{\partial \phi}{\partial x} + fv + F_x$$

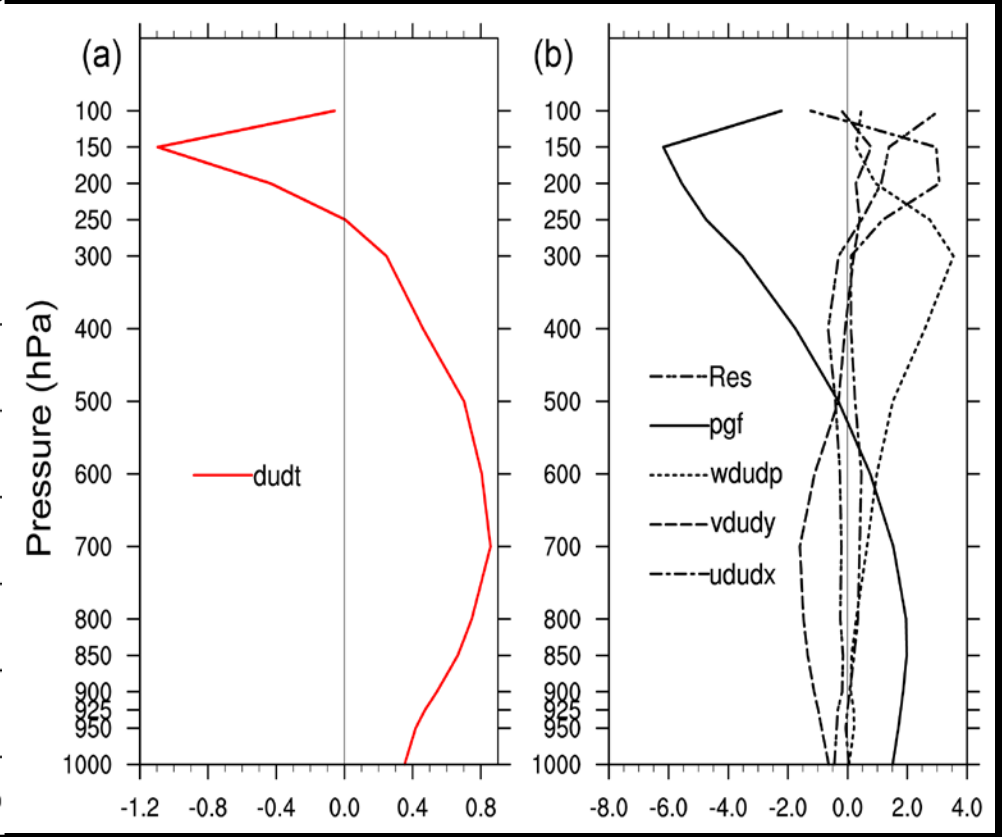
Analysis domain:
Northern Array (NA: 73-80E, Eq-5N)



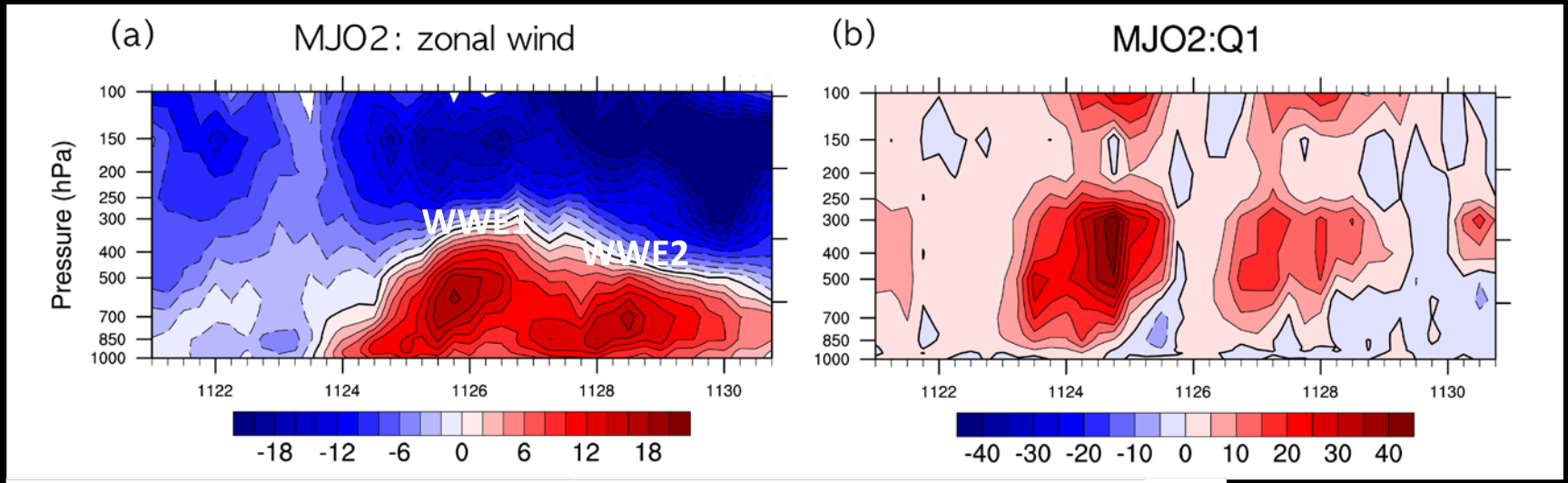
	Period	Resolution
ECMWF analysis	DYNAMO 2011: 01OCT-31DEC	0.25 degree 6-hourly

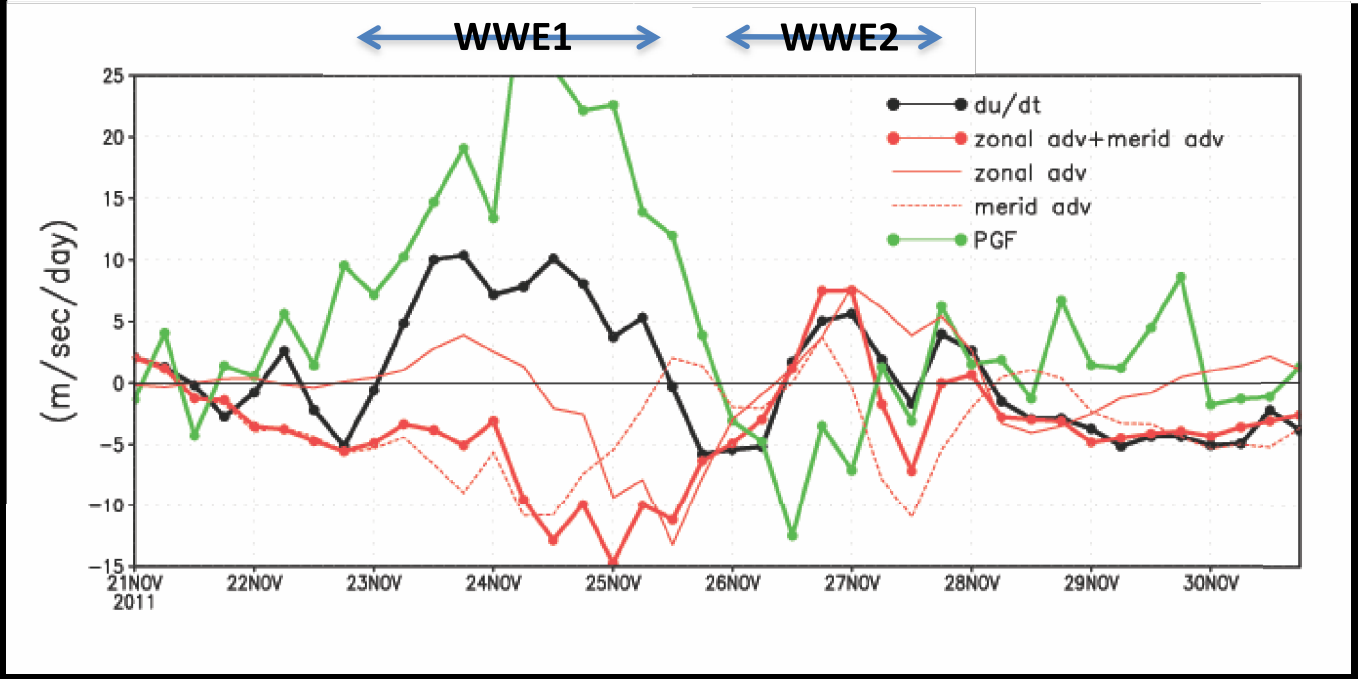


- Momentum budget analysis



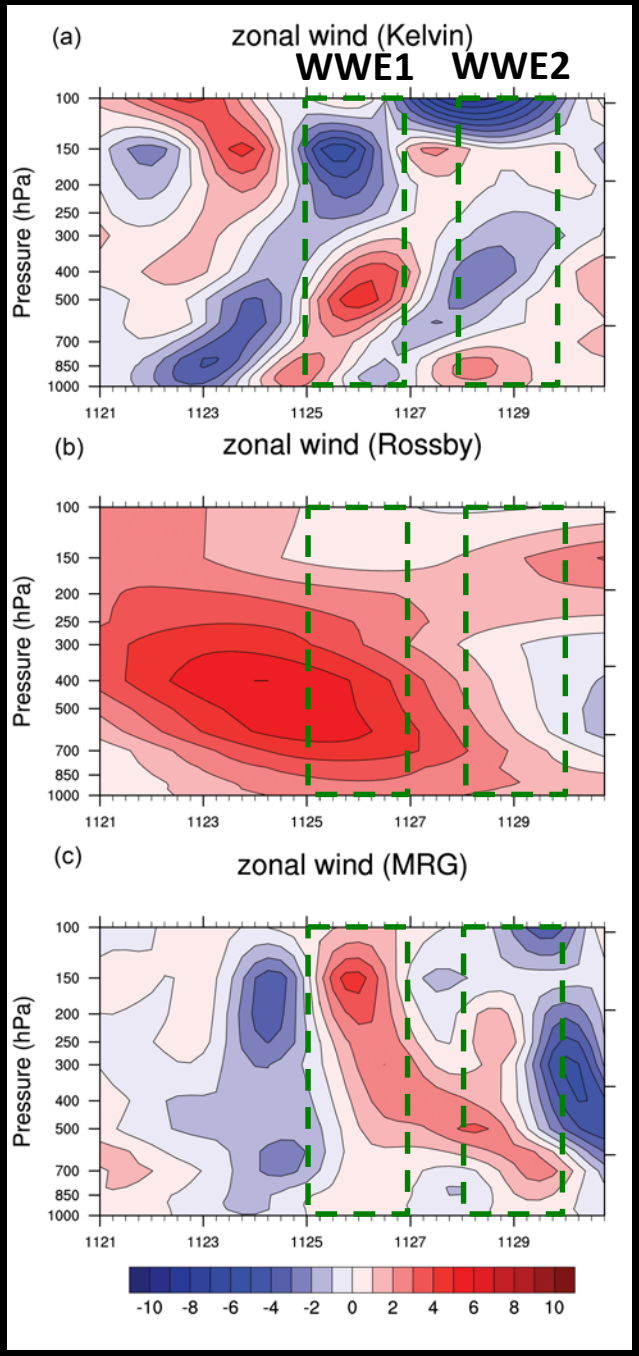
Case study





Time series of individual terms of zonal momentum budget averaged between 1000 hPa and 700 hPa over the NA

Different kinematic processes could bear on the occurrence of WWEs



Dynamical contribution of synoptic scale equatorial waves to the WWEs during MJO2

Concluding remark

Part 1.

- Three-layer vertical structure of CMT associated with the MJO: opposite in sign with respect to scale, balancing each other.
- The results can be applied to implement the vertical structure of the CMT into CMT parameterization of GCMs to improve the MJO prediction skill.

Part 2.

- Three dominant terms inducing WWEs in momentum budget analysis: PGF, vertical advection, meridional advection
- But, different kinematic processes could bear on the occurrence of WWEs (interplay of CCEWs).