Use of TRMM and DYNAMO data sets for addressing a mechanism of the MJO

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THIS STUDY INCLUDES THE :

1. The dynamo period 1 October 2011 to 15 December 2011.

2. The TRMM 3B42 data sets at 6 hourly intervals for this period for rainfall estimates.

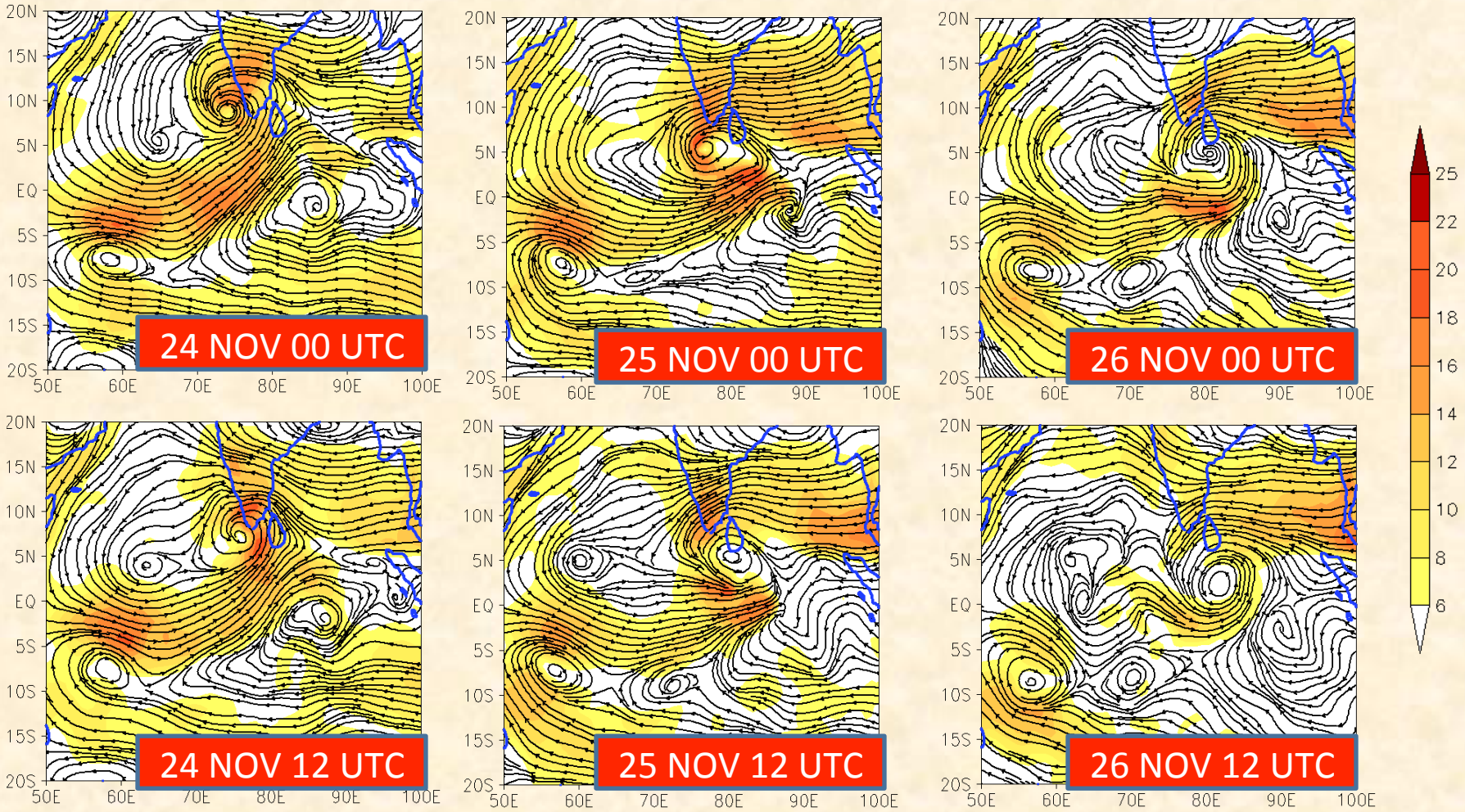
3. The dynamo ship radar reflectivity and rain rate estimates during the Intensive Observation period (IOP).

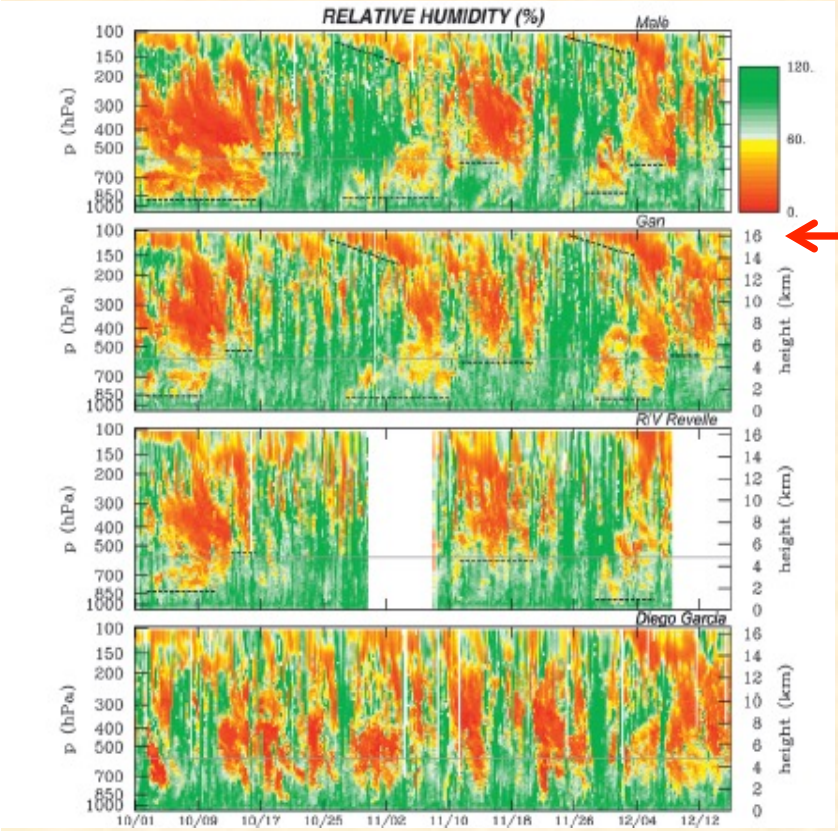
4. we use ERA- 40 plus FSU physical initialization to incorporate rains within a WRF model during the IOP of dynamo which covers the period November 2011 .

5. we perform high resolution box energetics to examine in scale processes , the organization of convection, the generation of available potential energy and the transformation of eddy available potential energy into the eddy kinetic energy for an IOP inner domain of DYNAMO. This addresses the maintenance of synoptic scale disturbances during the intensive observation period.

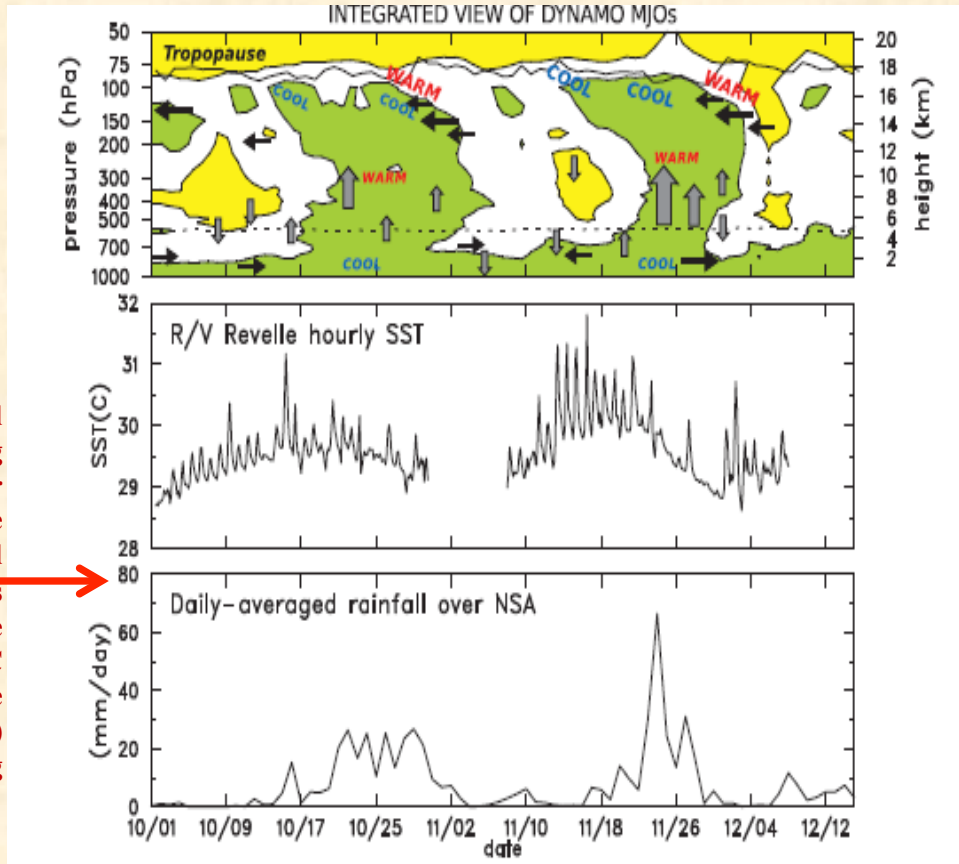
6. we next utilize global data sets to examine formal scale interactions among many scales. the main question we ask is on the energy that the MJO space-time scale receives for its maintenance.

Streamlines and isotachs at 850 hPa during IOP of DYNAMO



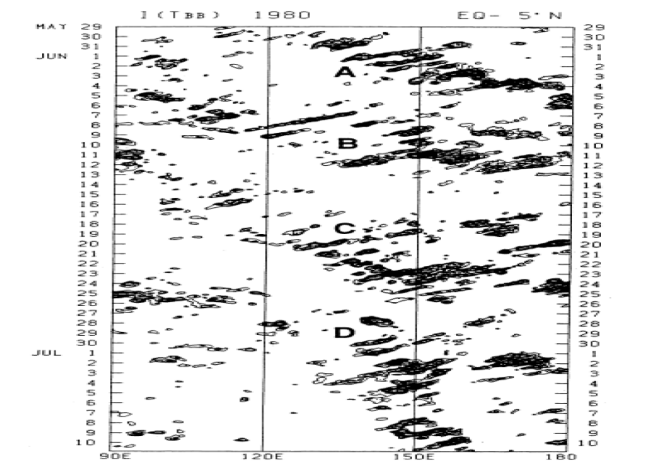


Time series of relative humidity (%; with respect to ice for T< 0°C) from 1 Oct to 15 Dec at Male, Gan Island, R/V Revelle and Diego Garcia based on full time resolution of sounding data. Dotted line segments denote approximate tops of moist layers. Thin gray line denotes 0°C level.

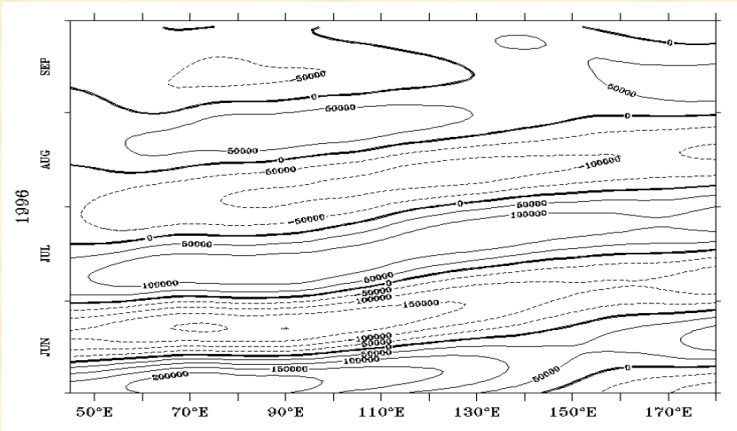


Integrated depiction of vertical structure of two MJOs during the period 1 Oct–15 Dec 2011 based on mean fields over the northern sounding array. Green (yellow) shading denotes areas of relative humidity greater than 70% (less than 40%), respectively. Thin (thick) arrows denote locations of zonal wind (vertical motion) maxima. Centers of cool and warm temperature anomalies are shown. Relative magnitudes of features are represented by sizes of symbols. At upper levels, these anomalies have a tilted structure as do the easterly wind maxima. Daily averaged 0°C level (dashed line) and cold-point tropopause level (solid line) are indicated. (middle) Hourly SST time series at R/V Revelle . (bottom) TRMM 3B42 daily averaged rainfall rate over the northern sounding array.

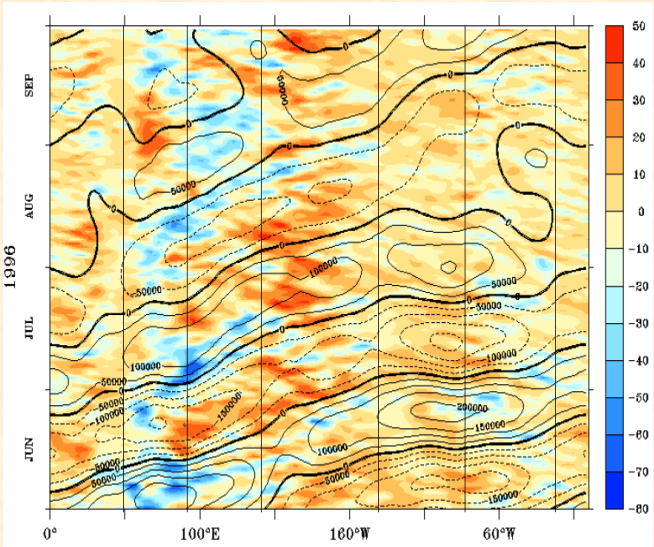
Johnson and Ciesielski, 2013, J.Climate



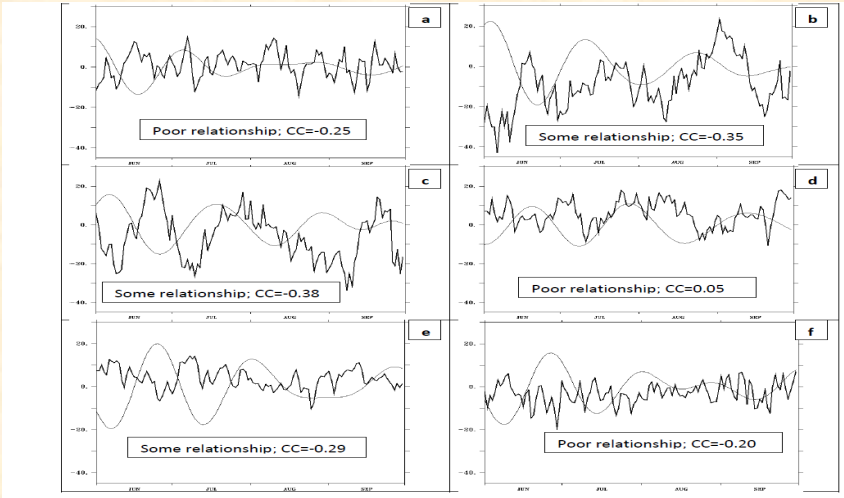
Time-longitudes ection of TBB index (ITBB) integrated between the equator and 5oN obtained from the 3-hourly GMS IR data from 29 May 00Z to 10 July 21Z, 1980. Symbols A to D denote the super clusters. Contour interval is 10, and shading denotes the region where values are greater than 20 (Adapted from Nakazawa, 1988).



Time-longitude section of filtered 200hPa velocity potential on a Hovmöller diagram for 122-days period during summer of 1996 in the equatorial belt 10°S to 10°N.



Variability of filtered velocity potential (contour) and unfiltered OLR anomaly (shaded) for summer season of year 1996.



Variability of filtered velocity potential (Light line) and unfiltered OLR anomaly (Dark line) for summer season of year 1996; (a) Africa region (0°E-50°E, 10°S-10°N) (b) Indian region (50°E-90°E, 10°S-10°N) (c) Western Pacific region (90°E-140°E, 10°S-10°N) (d) Central Pacific region (140°E-220°W, 10°S-10°N) (e) Eastern Pacific region (220°W-280°W, 10°S-10°N) (f) Central Pacific region (280°W-340°W, 10°S-10°N).

Krishnamurti et al. 2015 , AMS Monograph

Energy Equations

$$K_Z = \int_{p1}^{p2} \frac{\overline{[u]^2 + [v]^2}}{2g} dp \qquad \text{(A1)}$$

$$A_Z = \int_{p1}^{p2} \frac{\overline{[T]^{*2}}}{2\bar{\sigma}} dp \qquad \text{(A2)}$$

$$C_Z = -\int_{p1}^{p2} \frac{R}{p} \overline{[\omega]^* [T]^*} \frac{dp}{g} \qquad \text{(A3)}$$

$$K_E = \int_{p1}^{p2} \frac{\overline{[u'^2 + v'^2]}}{2g} dp \qquad \text{(A4)}$$

$$A_E = \int_{p1}^{p2} \frac{\overline{[T'^2]}}{2\bar{\sigma}} dp \qquad \text{(A5)}$$

$$C_k = C_{k1} + C_{k2} + C_{k3} + C_{k4}$$

$$= -\int_{p1}^{p2} \overline{[u'v']} \frac{\partial [u]}{\partial y} \frac{dp}{g} - \int_{p1}^{p2} \overline{[u'\omega']} \frac{\partial [u]}{\partial p} \frac{dp}{g} - \int_{p1}^{p2} \overline{[v'^2]} \frac{\partial [v]}{\partial y} \frac{dp}{g} - \int_{p1}^{p1} \overline{[v'\omega']} \frac{\partial [v]}{\partial p} \frac{dp}{g}$$

(A6)

$$C_{pk} = -\int_{p1}^{p2} \frac{R}{p} \overline{[\omega' T']} \frac{dp}{g} \qquad \text{(A7)}$$

$$C_A = C_{A1} + C_{A2}$$

$$= -\int_{p1}^{p2} \frac{\overline{[v'T']}}{\bar{\sigma}} \frac{\partial [T]}{\partial y} dp - \int_{p1}^{p2} \frac{\overline{[\omega'T']}}{\bar{\sigma}} \frac{\partial [T]}{\partial p} dp \qquad \text{(A8)}$$

$$\boxed{G_E = \int_{p1}^{p2} \frac{\overline{[T'Q']}}{\bar{\sigma} c_p} dp \qquad \text{(A9)}}$$

$$D_E = -\int_{p1}^{p2} \overline{\left[u'F_x' + v'F_y'\right]} \frac{dp}{g} \qquad \text{(A10)}$$

$$K_{EB} = \frac{1}{L_x} \int_{p1}^{p2} \left[\left(\frac{\overline{u(u'^2 + v'^2)}}{2g} \right)_{x1} - \left(\frac{\overline{u(u'^2 + v'^2)}}{2g} \right)_{x2} \right] dp$$

$$+ \frac{1}{L_y} \int_{p1}^{p2} \left(\left[\frac{\overline{v(u'^2 + v'^2)}}{2g} \right]_{y1} - \left[\frac{\overline{v(u'^2 + v'^2)}}{2g} \right]_{y2} \right) dp$$

$$+ \left(\left[\frac{\overline{\omega(u'^2 + v'^2)}}{2g} \right]_{p1} - \left[\frac{\overline{\omega(u'^2 + v'^2)}}{2g} \right]_{p2} \right) \qquad \text{(A11)}$$

$$\Phi_{EB} = \frac{1}{L_x} \int_{p1}^{p2} \left(\left(\overline{u'\phi'} \right)_{x1} - \left(\overline{u'\phi'} \right)_{x2} \right) \frac{dp}{g} + \frac{1}{L_y} \int_{p1}^{p2} \left(\left[\overline{v'\phi'} \right]_{y1} - \left[\overline{v'\phi'} \right]_{y2} \right) \frac{dp}{g} + \frac{1}{g} \left(\left[\overline{\phi'\omega'} \right]_{p1} - \left[\overline{\phi'\omega'} \right]_{p2} \right) \qquad \text{(A12)}$$

$[(\ )]$ represents a zonal mean and $\overline{[(\ )]}$ represents a meridional mean of the zonal mean. Primes indicate deviations from the zonal mean, and asterisks indicate deviations from the area mean. The relationships are $(\ ) = [(\ )] + (\ )'$ and $[(\ )] = \overline{[(\ )]} + (\ )^*$. Variables not mentioned in the text: K_Z is zonal kinetic energy, A_Z is zonal available potential energy, C_Z represents conversions between the two.

Following are the definitions of variables:

u: zonal wind component, positive to the east

v: meridional wind component, positive o the north

ω: vertical pressure velocity

T: temperature

p: pressure

F_x: friction in the zonal direction

F_y: friction in the meridional direction

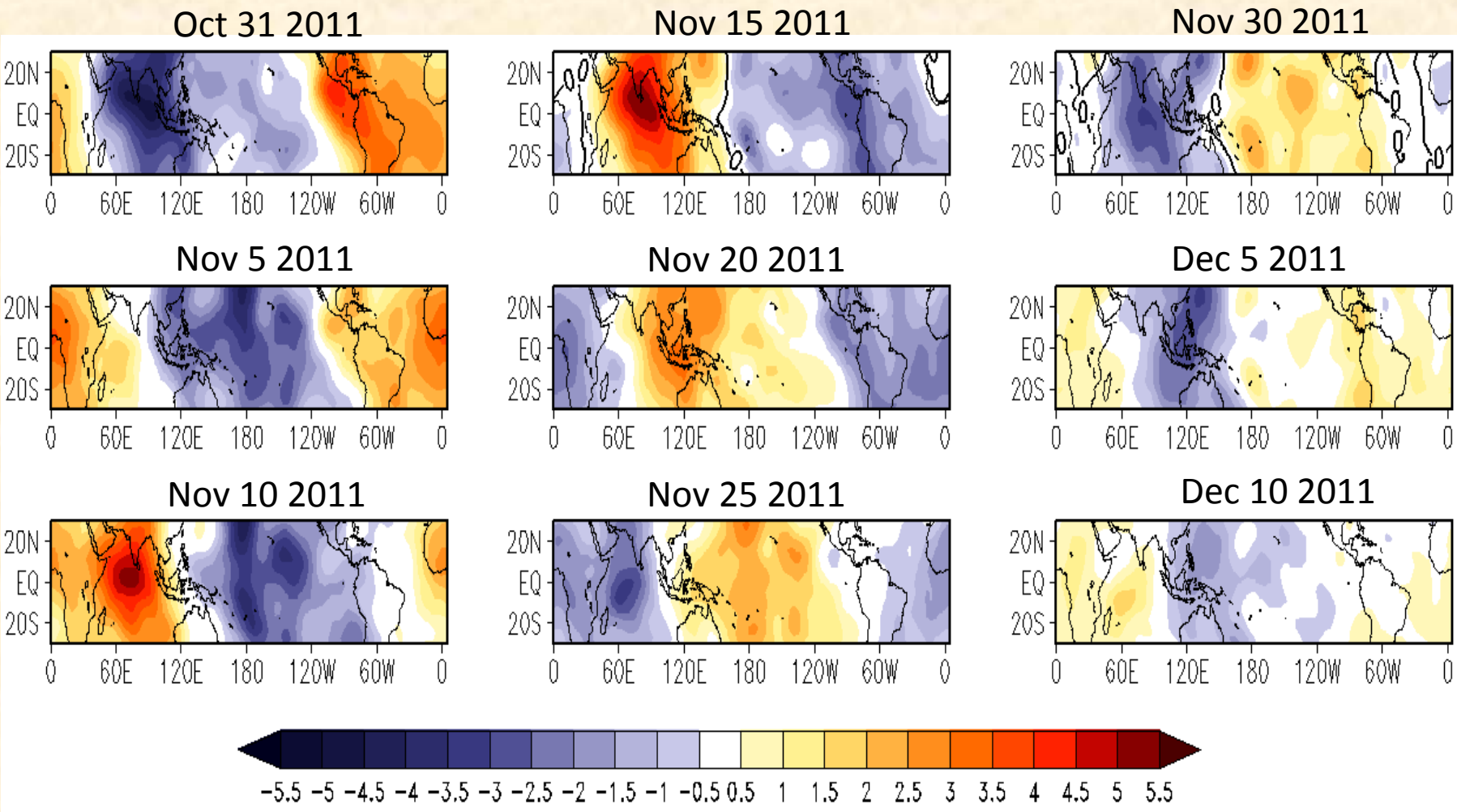
Q: diabatic heating

ϕ: geopotential

$\overline{\sigma}$: mean static stability ($g c_p^{-1} \overline{[T]}$ - $gp R^{-1} \partial \overline{[T]} \partial p^{-1}$)

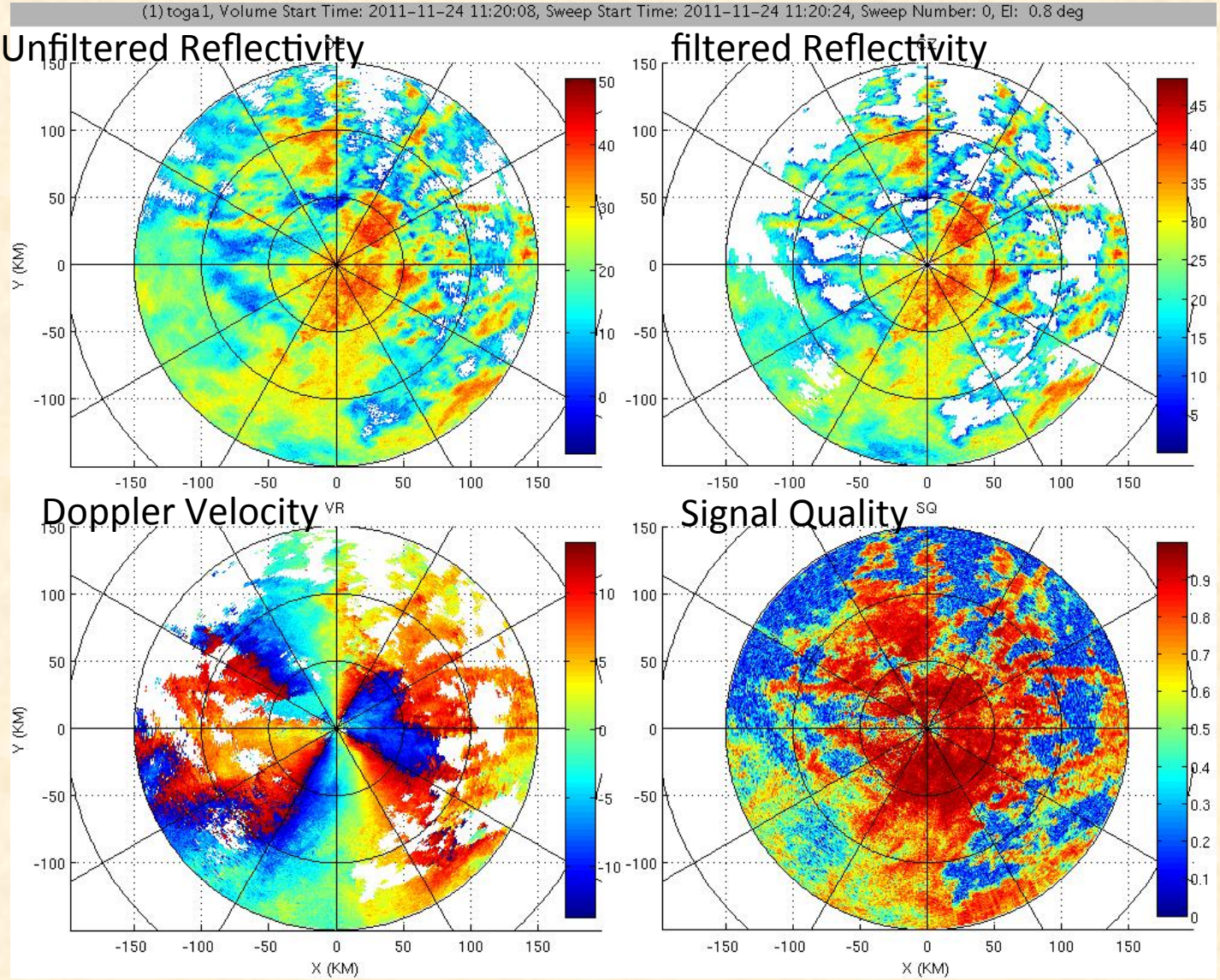
c_p: specific heat at constant pressure

Velocity Potential at 200mb on the time scale of ISO



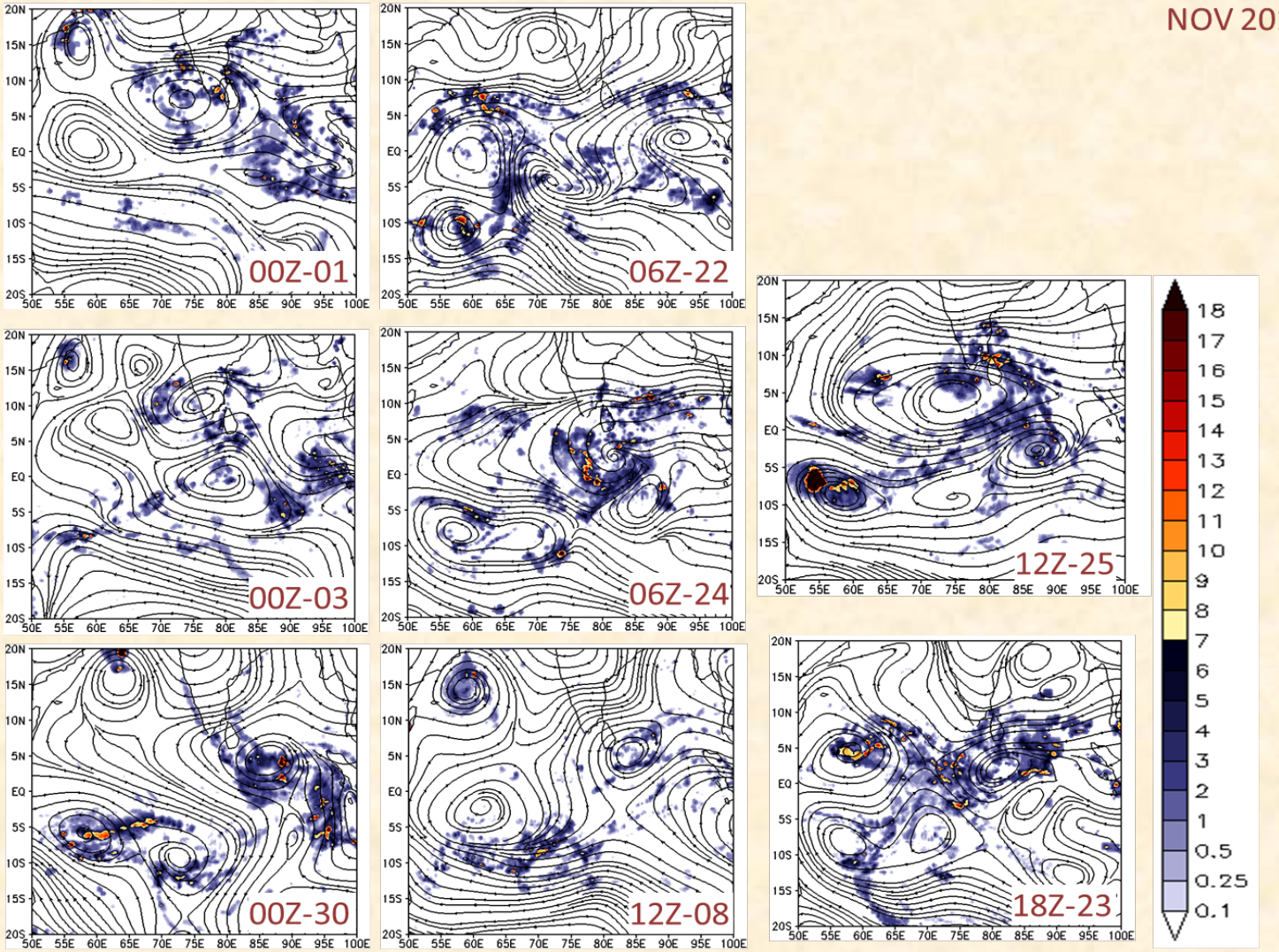
Passage of MJO around the world during the IOP of DYNAMO

Ship board radar during DYNAMO



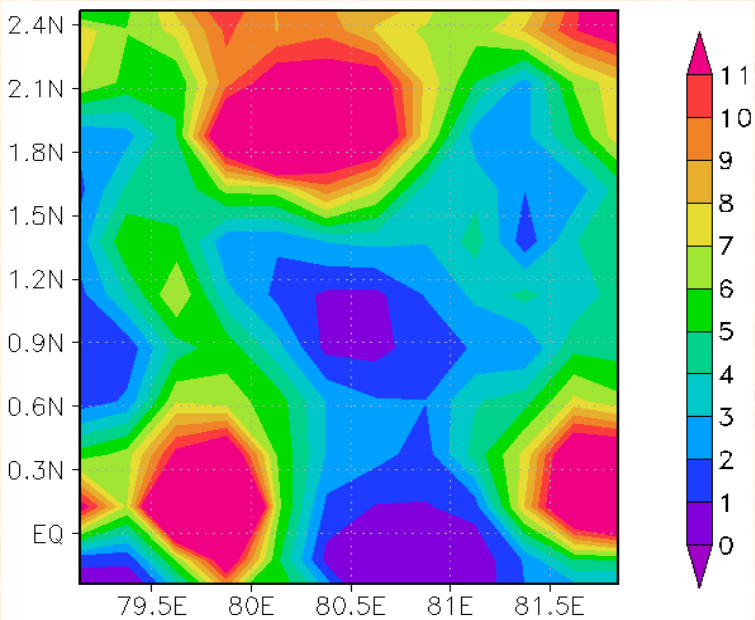
Organization of Convection

NOV 2011

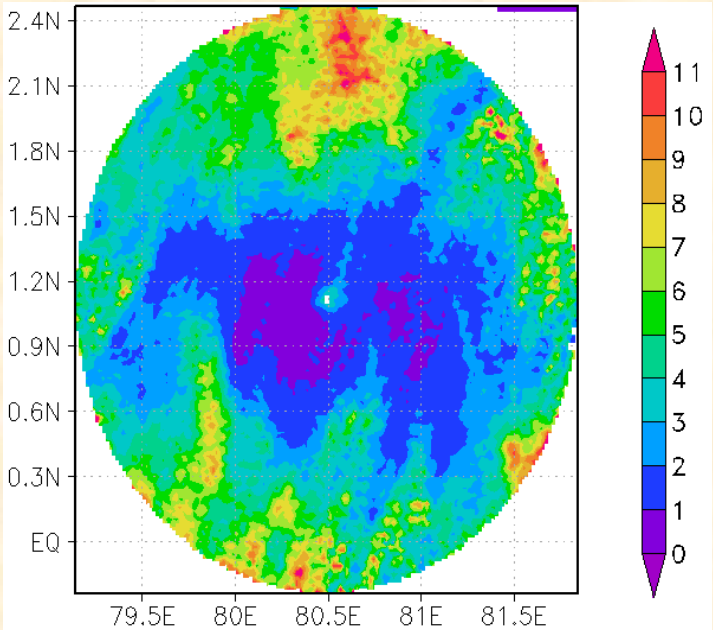


Organization of convection on the synoptic scale (850 hPa streamline) during the IOP of DYNAMO Precipitation is shaded.

TRMM Rainfall (mm)-3hr



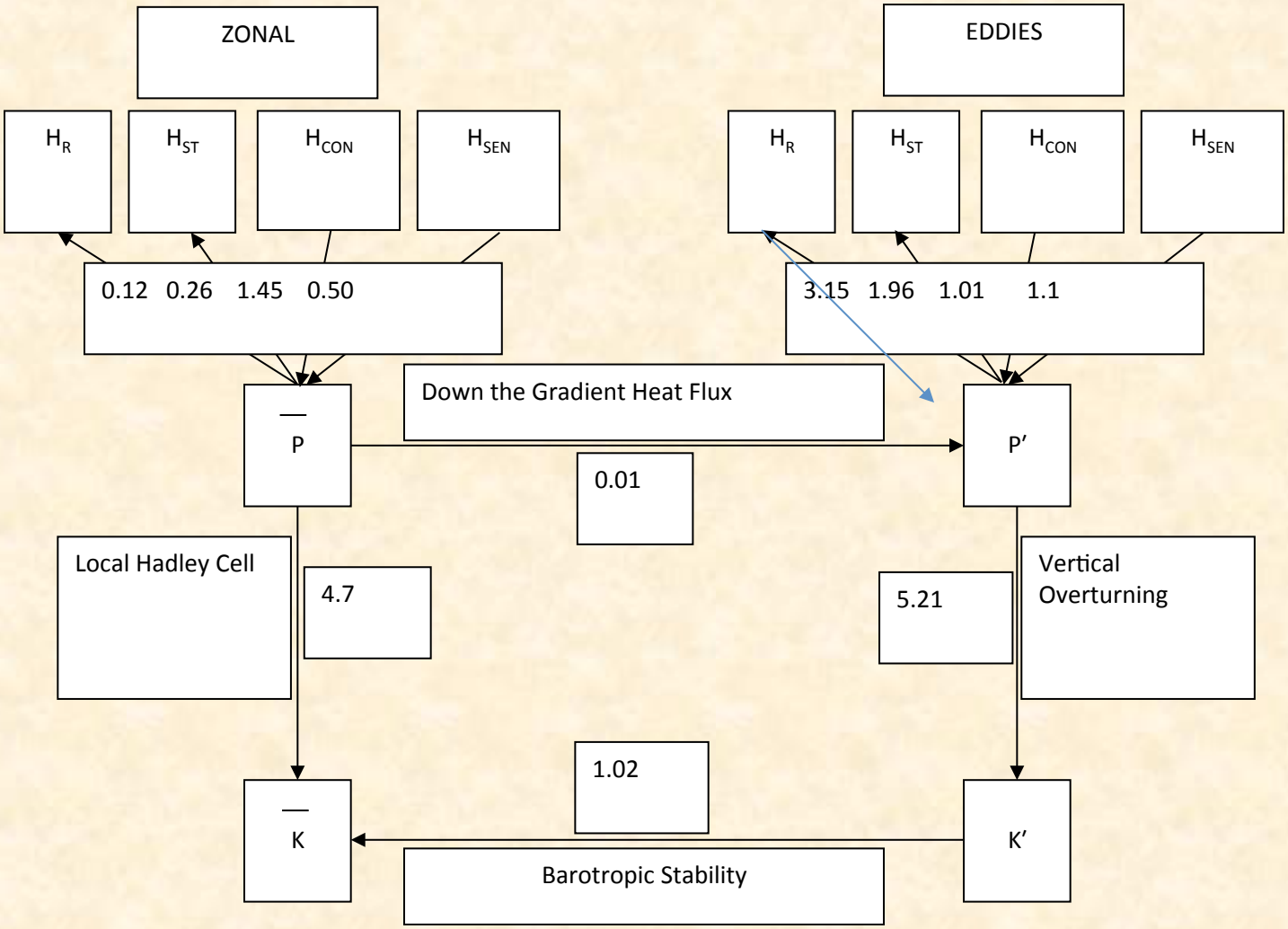
DYNAMO-TOGA Radar Rainfall (mm)-3hr



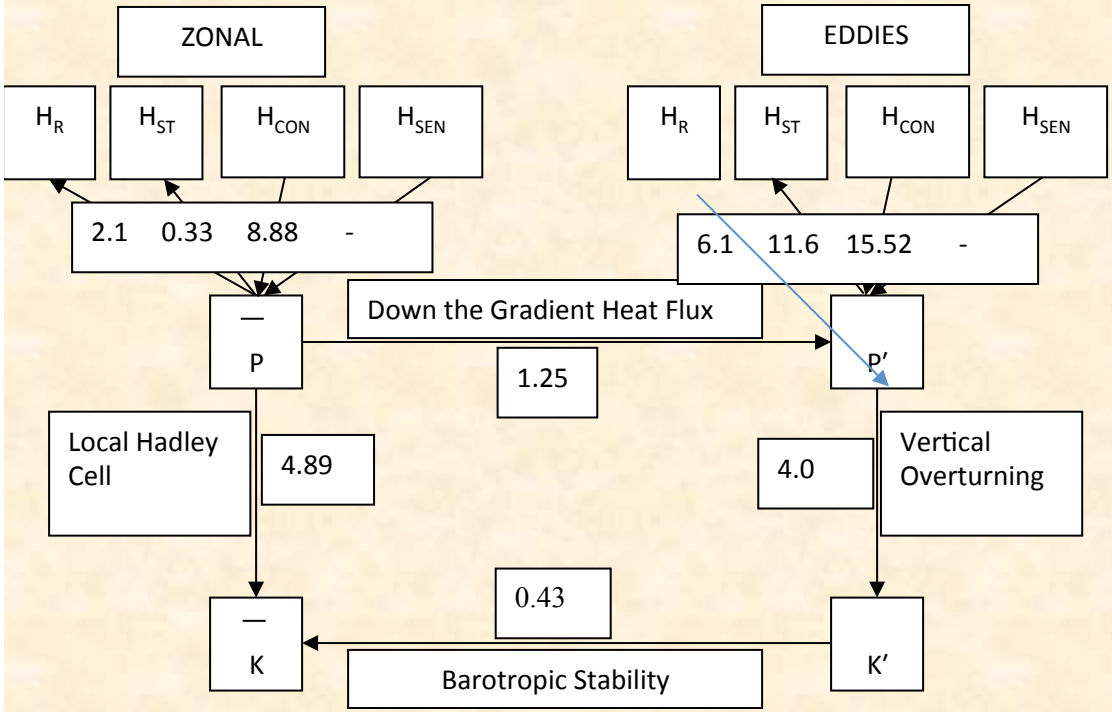
10 Nov 2011

comparison of TRMM and radar rain during IOP of DYNAMO.

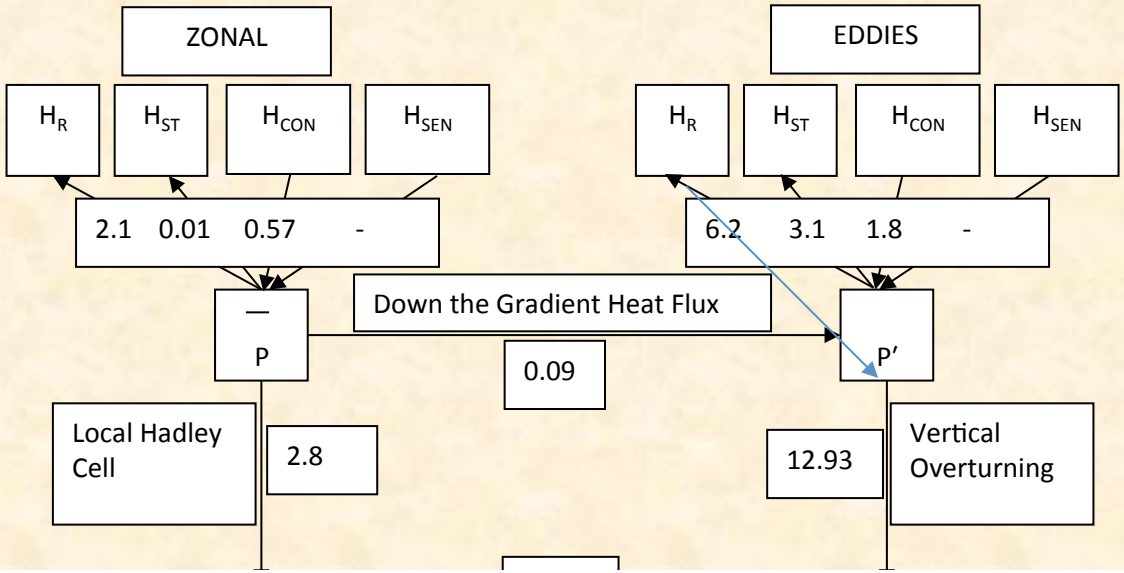
Energy exchange based on observational datasets on Nov 7 2011



Energy Exchange based on control simulation on Nov 7 2011



Energy Exchange based on Physical Initialization on Nov 7 2011



Scale Interactions

Nonlinear Kinetic energy transfer in Frequency Domain

Nonlinear Kinetic energy transfer into frequency n by interaction among different frequencies excluding 0 frequency : $< \mathbf{K}_m \cdot \mathbf{K}_n >$

$$\langle K_m \cdot K_n \rangle = -\left[P_n\left(u, \frac{\partial u'u'}{\partial x}\right) + P_n\left(v, \frac{\partial u'v'}{\partial x}\right) + P_n\left(u, \frac{\partial u'v'}{\partial y}\right) + P_n\left(v, \frac{\partial v'v'}{\partial y}\right)\right]$$
$$+ \frac{\tan\theta}{a}\left[P_n(u, u'v') - P_n(v, u'u')\right] - \left[P_n\left(u, \frac{\partial u'\omega'}{\partial p}\right) + P_n\left(v, \frac{\partial v'\omega'}{\partial p}\right)\right]$$

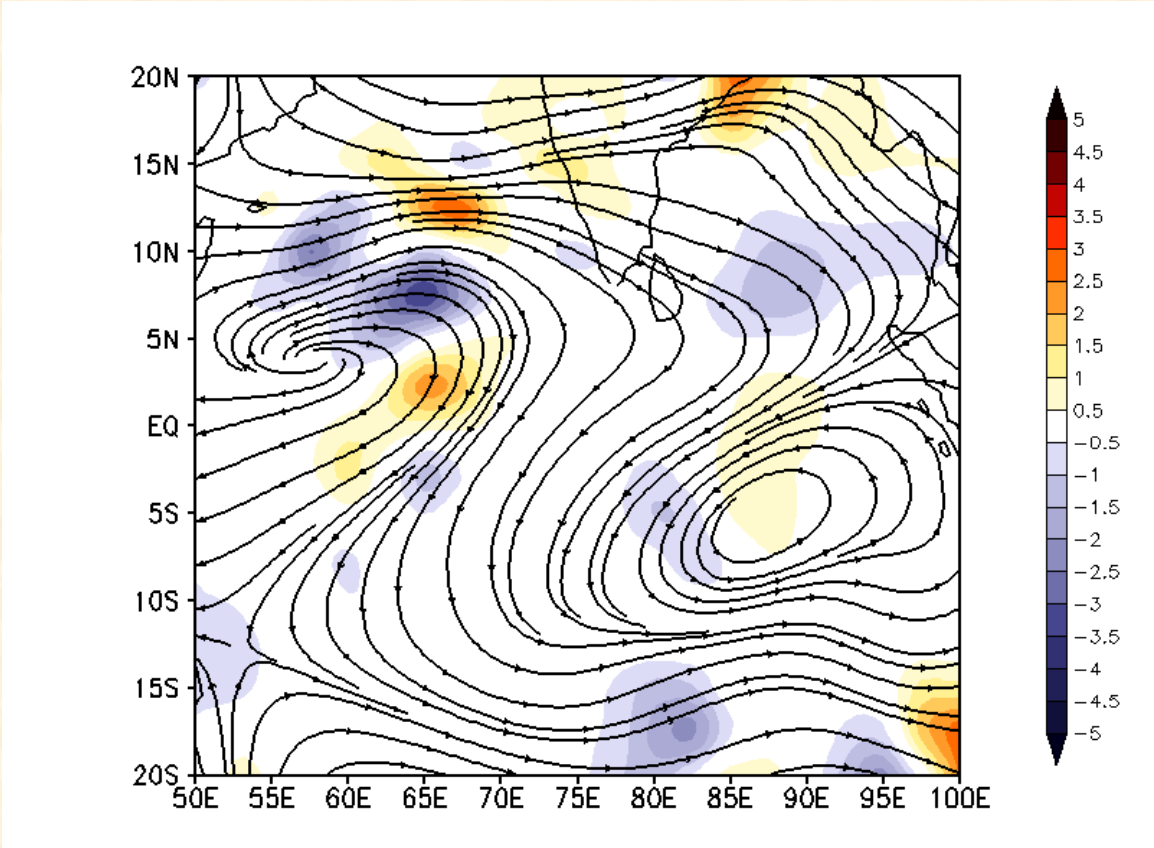
Cospectrum $\mathbf{P_n(A,BC)}$ is defines as:

$$\sum_{m=-N}^{N-n} 1/4 \;\; A_n^* B_m^* C_{n+m}^*$$

Where N is Nyquist frequency.
A transfer occurs only when frequencies n, m and n ± m are related as
n = (n ± m) ∓ m.

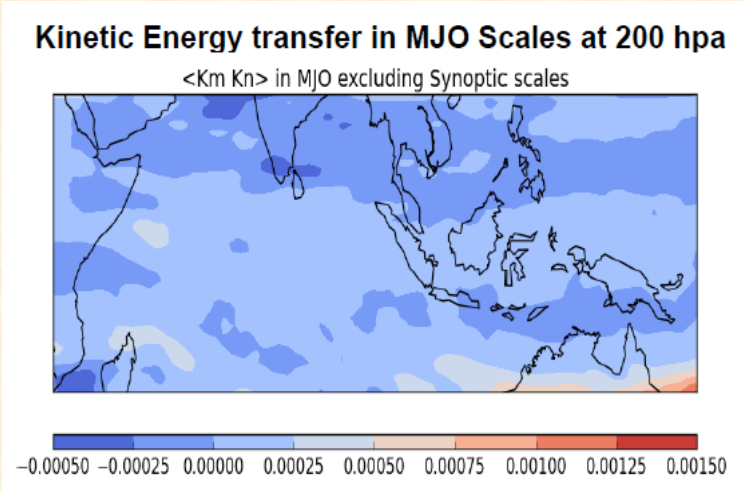
Jian Sheng and Yoshikazu Hayashi, 1990, JAS

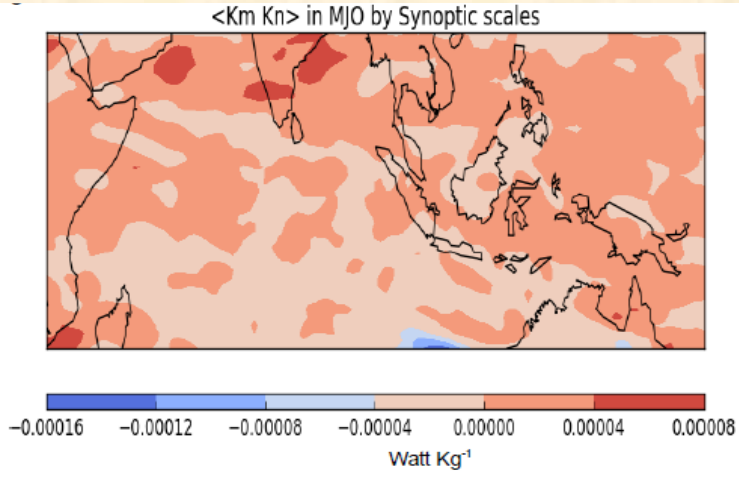
Convergence of flux of momentum at 850mb



Streamlines at 200 hpa in black and precipitation (shaded)

The convergence of flux of momentum from the synoptic scales strengthens or weaken the westerlies or easterlies of the MJO time scale. This is what leads to a strengthening of the MJO by energy transfers from the synoptic scale, and thus contributing to the maintenance of the MJO.





The blue coloring shows the energy exchanging (via scale interactions) from all scales (excluding synoptic scale) to the MJO , the next panel with red coloring shows the energy exchange from all the permissible synoptic scales to the MJO. *These results are still being confirmed.*

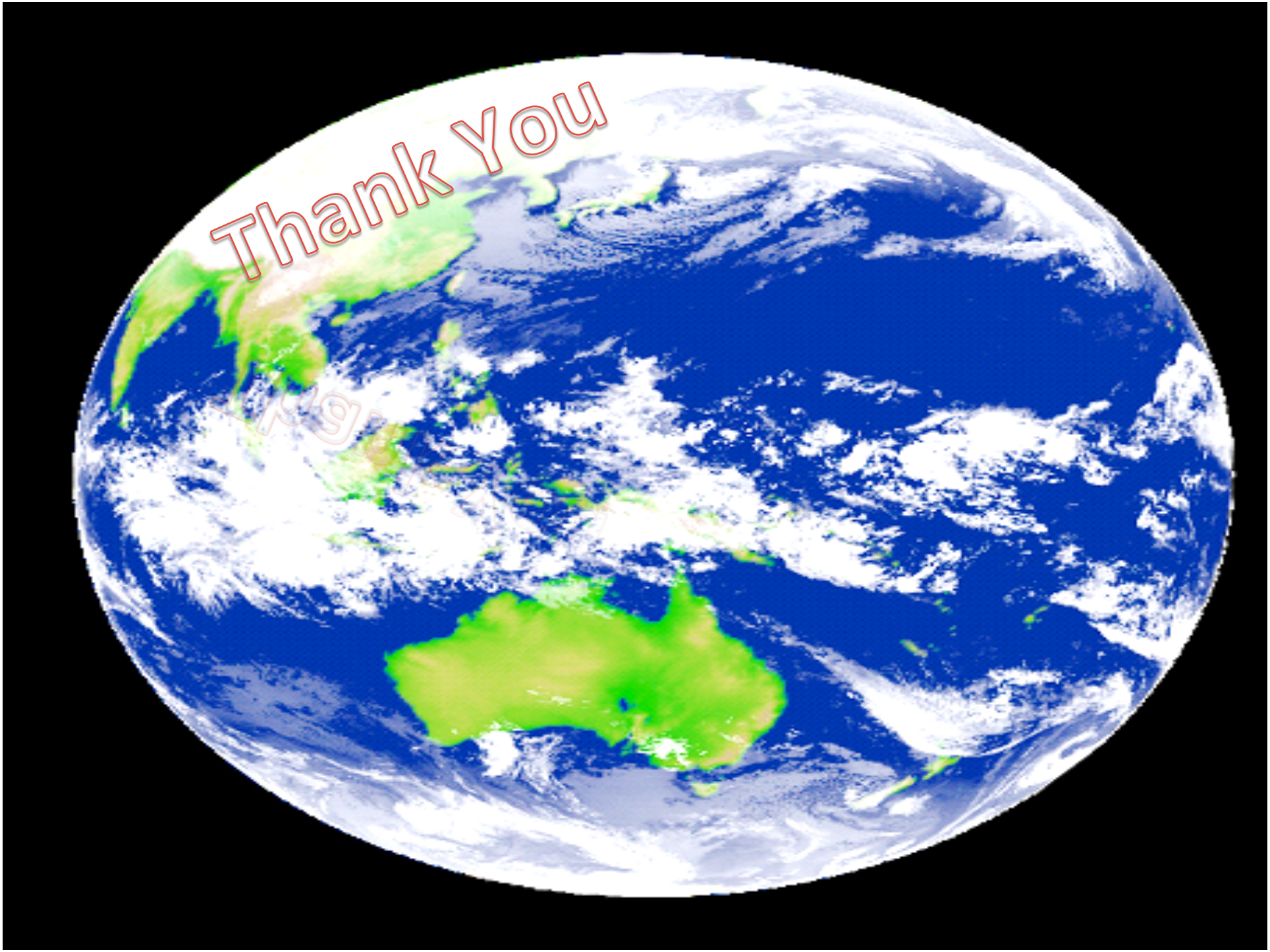
CONCLUDING REMARKS

Our mechanism for the MJO contains three major parts:

1. Rain rate initialization is necessary to initialize cloud resolving models that show an organization of convection on the scale of mesoscale disturbances of DYNAMO.

2. In-scale organization of convection, generation of available potential energy and its transformation to eddy kinetic energy all occur on the scales of synoptic disturbances. this implies that convection within the inner domain of dynamo plays a major role in the maintenance of synoptic scale near equatorial disturbances.

3. The synoptic scale convey energy for the maintenance of the MJO via dynamical scale interactions. These are *triad interactions* that carry energy exchanges from pairs of frequencies on the synoptic scale to one frequency of the MJO time scale. There are many such mathematically permissible triads that contribute to the maintenance of the MJO time scale. The synoptic scales are important for this maintenance.


Thank You