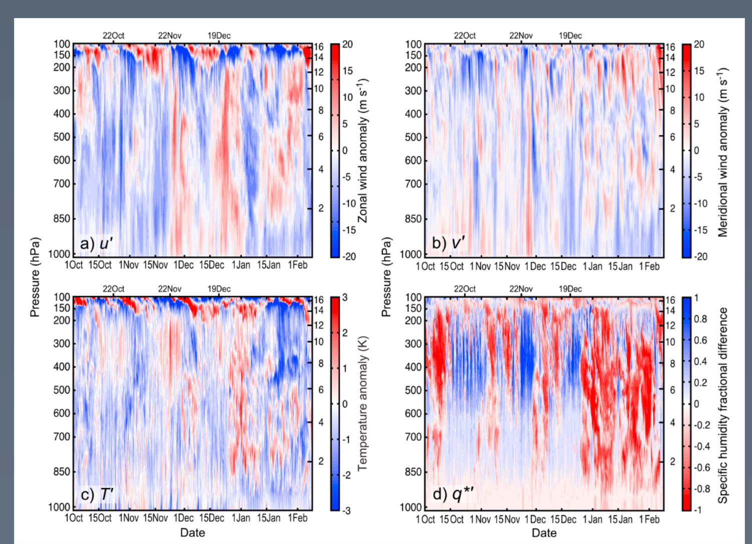
The Role of Upper-Tropospheric Dynamics in MJO Convective Onset[1]

Scott W. Powell and Robert A. Houze, Jr.
University of Washington, Seattle, WA

1. Introduction

- DYNAMO and AMIE observations recorded three convective outbreaks of the Madden-Julian Oscillation over the Indian Ocean in 2011.
- Powell and Houze (2013) have shown that a gradual "discharge-recharge" is not responsible for onset of widespread MJO-related convection during these events.
- Many studies, beginning with Knutson and Weickmann (1987), have indicated that upper-level negative velocity potential anomalies (divergence aloft) coincide with convective outbreaks.
- Velocity potential anomalies are tracked during AMIE by Gottschalck et al (2013). Widespread, organized convection over the Indian Ocean first occurs when divergence anomalies aloft approach from the west.
- Powell and Houze (2013) and Johnson and Ciesielski (2013) document 25-30 day variability in the zonal wind, temperature, and humidity anomalies in the upper troposphere using AMIE rawinsonde data from Gan Island.



2. Objectives and Data

Objectives

a) Show that radar observations taken near Gan Island during AMIE are consistent with the evolution of precipitating cloud echo depth throughout the central, equatorial Indian Ocean.

b) Demonstrate consistency between the evolution of zonal wind (*u*), temperature (*T*), and humidity (*q*) fields observed at Gan and over a large scale domain surrounding Gan.

c) Use reanalysis to document the longitudinal progression (if any) of zonal wind (*u*), temperature (*T*), and humidity (*q*) .

Data

Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar: Used to compare evolution of precipitation echoes over large-scale to those observed by S-PolKA.

S-PolKA: S-band precipitation radar active during DYNAMO/AMIE

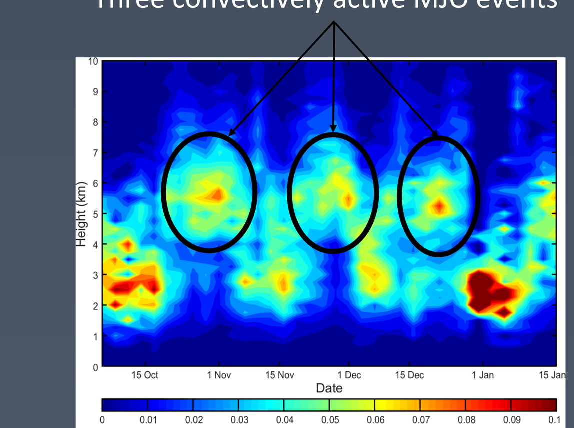
AMIE rawinsondes: Took 3-hourly measurements of wind, temperature, and humidity.

Atmospheric Infrared Sounder (AIRS): Used to demonstrate consistency between Gan humidity field and large-scale humidity field.

ERA-Interim: Reanalysis used to document zonal and meridional propagation of upper-tropospheric dynamic and thermodynamic anomalies. Output at 1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150, and 100 hPa used.

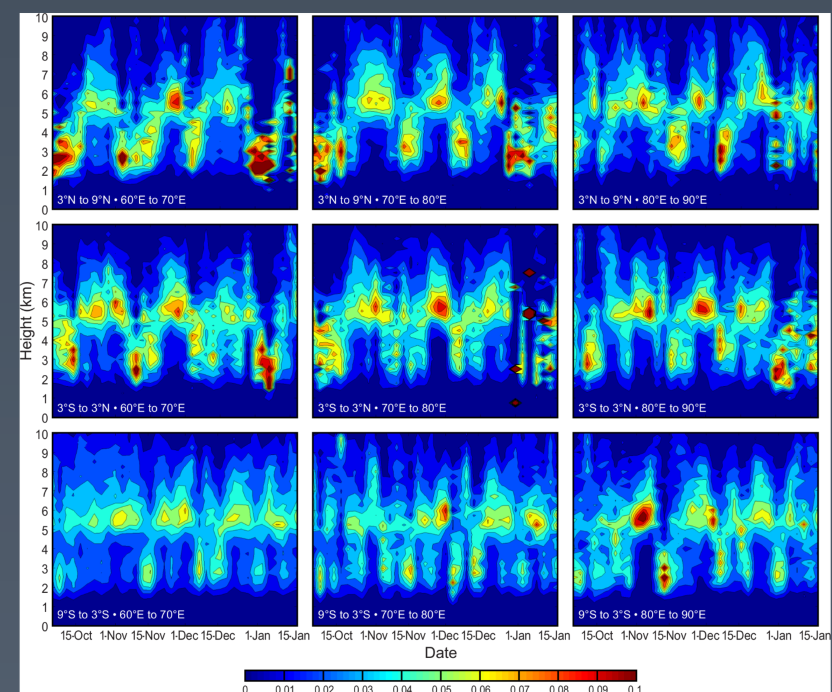
3. Large-Scale Representation of Radar Echoes and Dynamic/Thermodynamic Fields

Evolution of Echo Top Height Observed by TRMM*



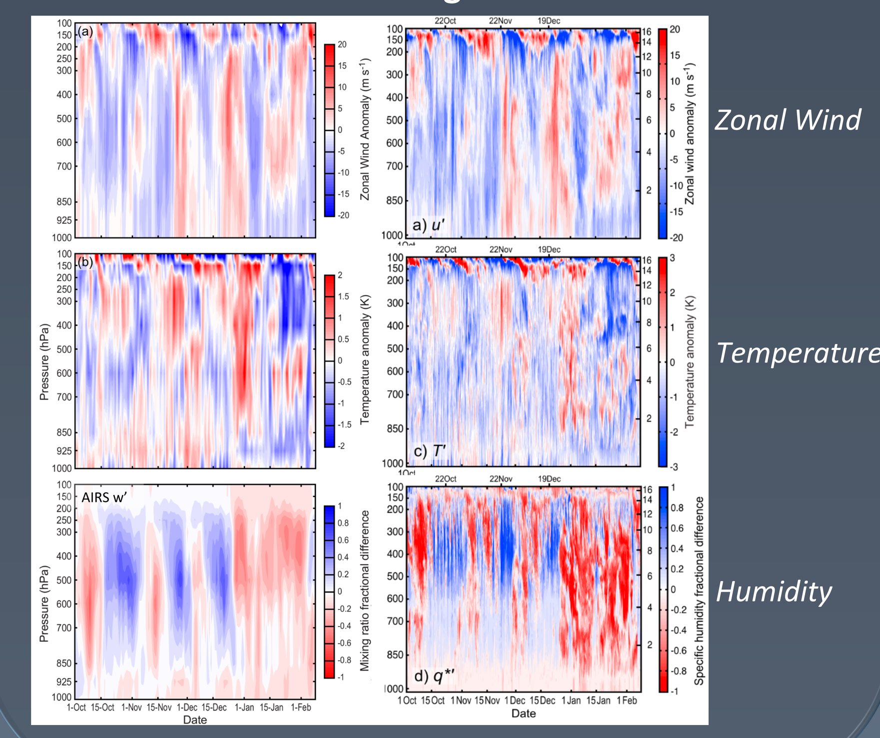
Top: Normalized probability of detection of 20 dBZ echo top for convective echoes composited between 3°N, 9°N, 68°E, and 78°E. 25–30 day variability in modal distribution is observed.

Right: Same for convective and stratiform echoes with regions indicated in each panel. 25–30 day variability observed near and north of equator but not south of equator close to ITCZ.



*Both time series are smoothed to 3-day intervals.

Gan Rawinsonde Profiles Consistent with Large-Scale



Evolution of Convective Echoes Prior to Outbreak[2]

Right: Histogram of 20 dBZ convective echo tops as observed by S-PolKa relative to a filtered maximum in precipitation for October and November 2011 MJO events. Large stratiform regions are observed first near -6 days, when the echo top height rapidly increases. Prior to this, the number and size of convective echoes increases; however, the modal depth of their 20 dBZ contour remains below 6 km.

Bottom: See caption for details. In general, convective echoes precede humidification at all levels and stratiform echoes precede upper-level moistening.

About a week before MJO convective onset over the Indian Ocean, convective echoes increase in number and size but not in modal depth. They primarily moisten the lower troposphere and are followed by stratiform regions that further moisten the upper troposphere.

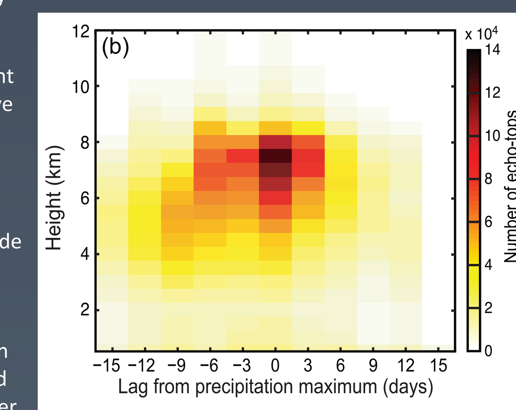


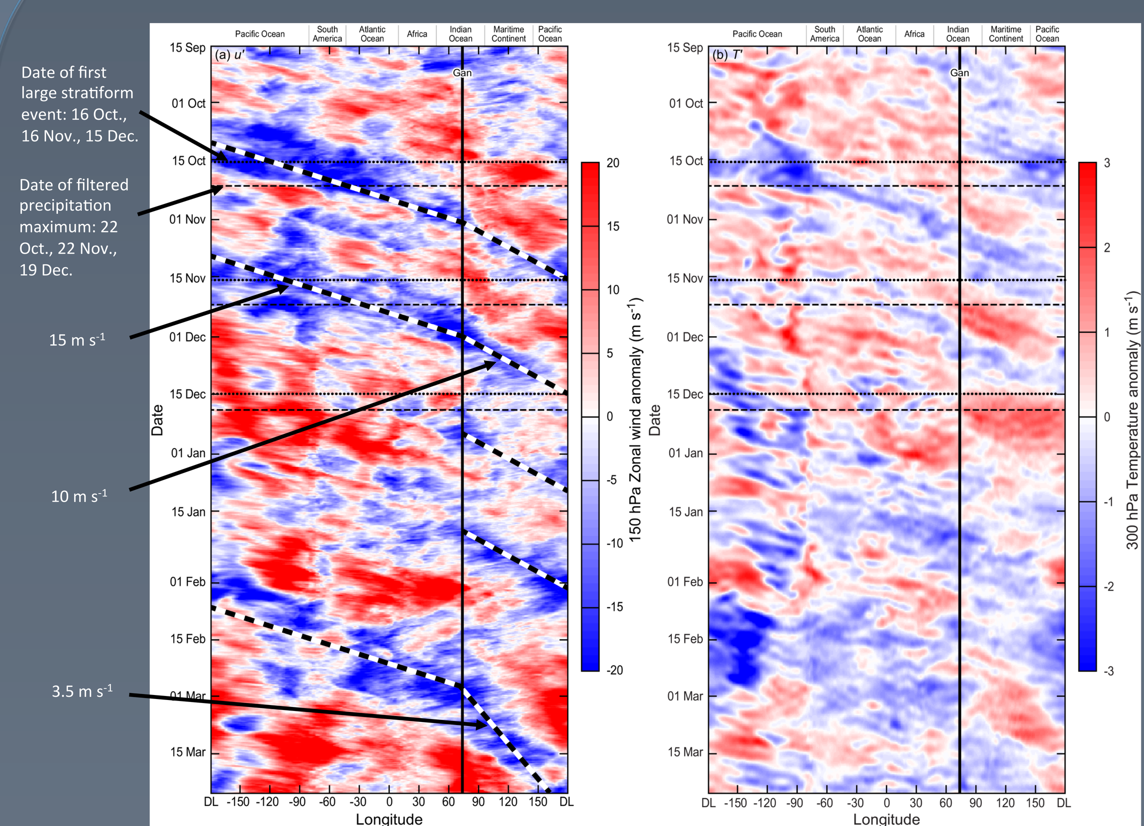
Table 3. Maximum Lagged Cross-Correlation Coefficients (With Lag in Hours in Parentheses) Between Convective/Stratiform Areal Coverage and Unfiltered, Unsmoothed Specific Humidity Anomalies for 1 October to 15 January Using Various Smoothing Periods[a]

		Smoothing Interval					
Var. 1	Var. 2	None	6 h	12 h	24 h	36 h	72 h
Conv	q'_{850}	**0.45 (0)**	**0.49 (0)**	**0.54 (0)**	**0.60 (0)**	0.61 (0)	**0.69 (0)**
Conv	q'_{700}	**0.50 (+3)**	**0.53 (0)**	**0.58 (0)**	**0.66 (0)**	**0.70 (0)**	**0.80 (0)**
Conv	q'_{500}	**0.49 (+6)**	**0.51 (+6)**	**0.54 (+12)**	**0.61 (+24)**	**0.61 (+36)**	0.73 (+72)
Conv	q'_{300}	**0.44 (+9)**	**0.47 (+6)**	**0.51 (+12)**	**0.50 (0)**	0.51 (+36)	0.59 (+72)
Strat	q'_{850}	**0.34 (−3)**	**0.37 (−6)**	0.39 (−12)	0.42 (−24)	0.46 (−36)	0.54 (−72)
Strat	q'_{700}	**0.45 (−3)**	**0.47 (0)**	0.50 (0)	**0.55 (0)**	**0.61 (0)**	**0.77 (0)**
Strat	q'_{500}	**0.55 (+3)**	**0.57 (0)**	**0.60 (0)**	**0.65 (0)**	**0.70 (0)**	0.76 (0)
Strat	q'_{300}	**0.52 (+3)**	**0.56 (0)**	**0.61 (0)**	**0.66 (0)**	**0.68 (0)**	**0.74 (0)**
Conv	Strat	**0.81 (+3)**	**0.80 (+6)**	**0.76 (0)**	**0.80 (0)**	**0.82 (0)**	**0.81 (0)**

[a]All correlation values that are in bold are statistically significant at the 95% level. Variables correlated are shown in columns 1 and 2. Positive lags indicate that Variable 1 comes first. (Conv = Convective areal coverage; Strat = Stratiform areal coverage).

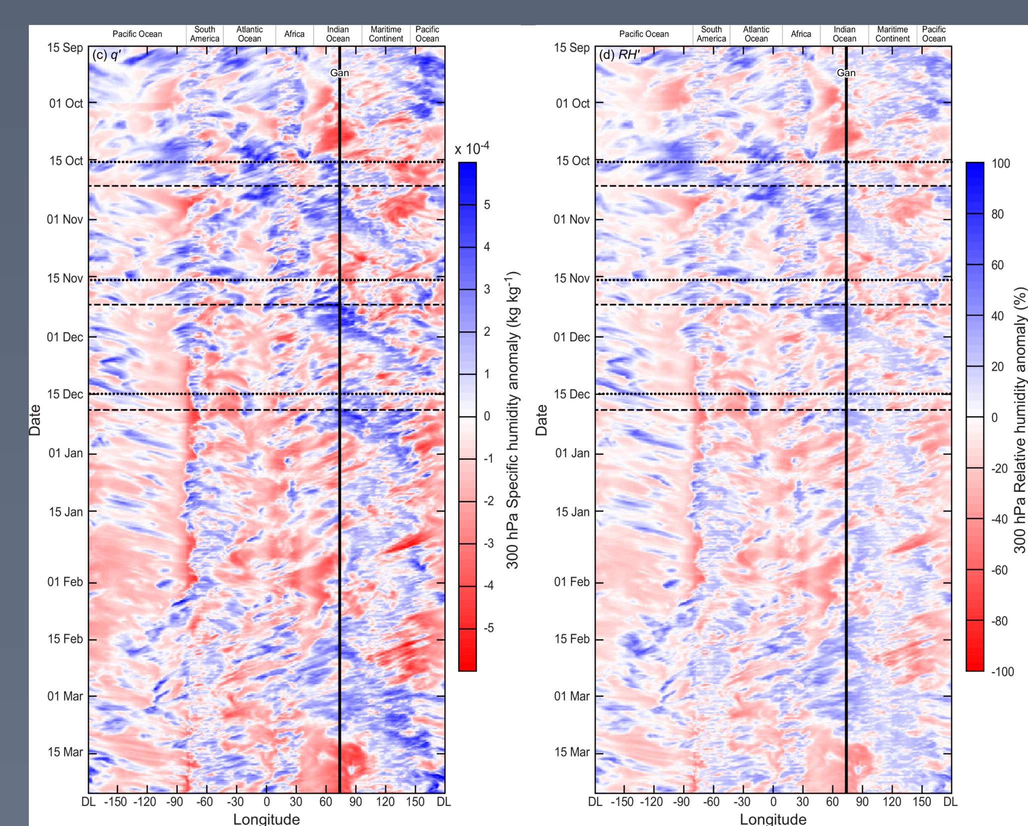
4. Eastward Propagating Zonal Wind, Temperature, and Humidity Anomalies

150 hPa Zonal Wind and 300 hPa Temperature



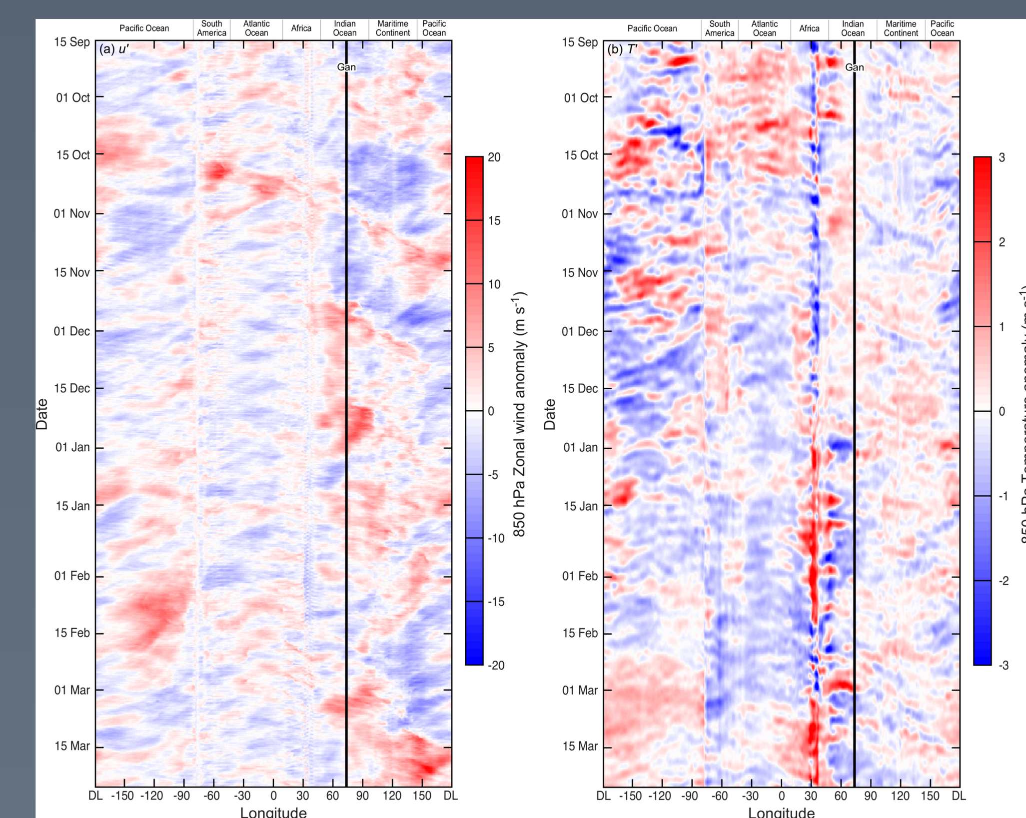
Left: Hovmöller for 150 hPa *u* anomaly. Right: Hovmöller for 300 hPa *T* anomaly. Easterly propagating anomalies of zonal wind and temperature move into Indian Ocean. Convective outbreak does not begin until divergent anomaly appears at 150 hPa. Propagation speed and relationship between structures of *u′* and *T′* confirm a Kelvin wave. Signal propagates more slowly eastward after convection is coupled to wave. *T′* is more in quadrature with *u′* after coupling, a signal of a forced Kelvin wave.

300 hPa Specific Humidity and Relative Humidity



Left: Hovmöller for 300 hPa *q* anomaly. Right: Hovmöller for 300 hPa *RH* anomaly. The two fields' signs look nearly identical. In the tropics, where temperature anomalies are generally quite small, the relative humidity anomaly is dominated by variability in moisture. Furthermore, positive humidity anomalies form where MJO convective events begin then propagate eastward. No precursor signal in humidity exists prior to MJO convective onset.

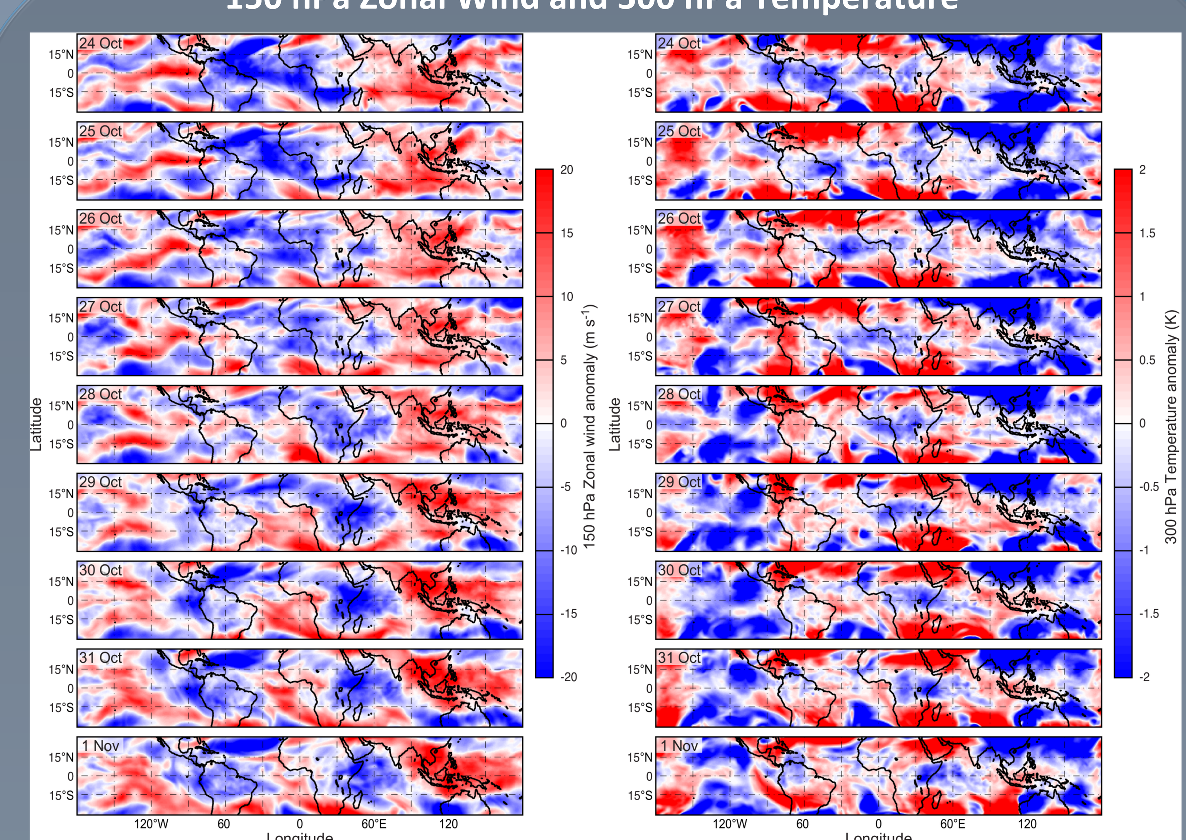
850 hPa Zonal Wind and Temperature



Left: Hovmöller for 850 hPa *u* anomaly. Right: Hovmöller for 850 hPa *T* anomaly. No lower tropospheric signal propagates into the Indian Ocean from the west prior to and at the beginning of MJO convective outbreaks, likely because topographic barriers prevent such propagation. Coherent 25–30 day variability in low-level winds is observed near and east of Gan, representing anomalous large-scale convergence associated with widespread convection, but no such signal is observed in the temperature field.

5. Plan Views of Propagating Zonal Wind and Temperature Anomalies

150 hPa Zonal Wind and 300 hPa Temperature



Left: 150 hPa *u′*. Right: 300 hPa *T′*. As large-scale anomaly of one sign propagates into Indian Ocean, it is confined to near equator at first. Anomaly spreads meridionally as wave becomes coupled to convection.

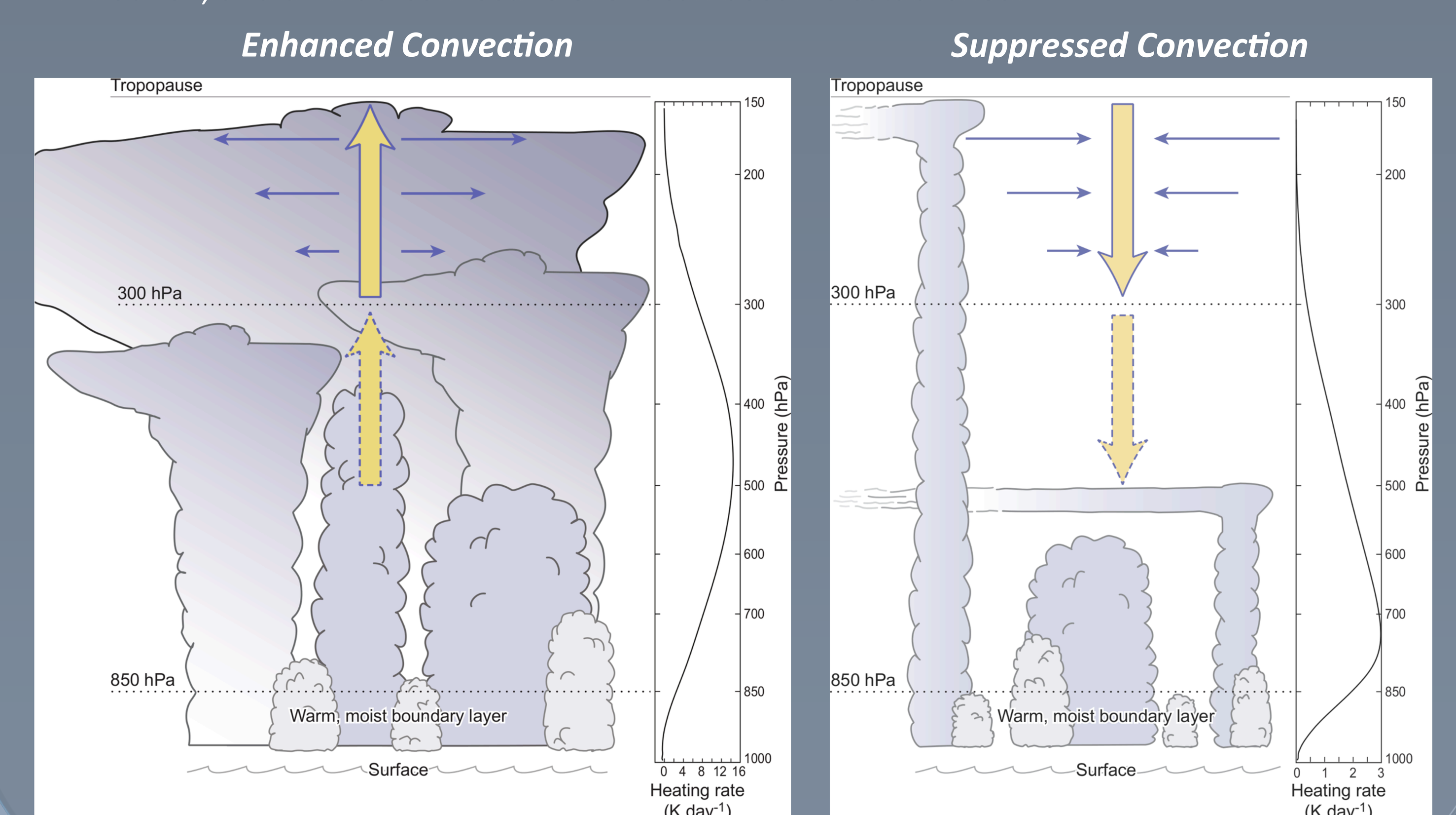
6. Conclusions

- S-PolKa observations of convective echo top height are consistent with TRMM observations, which indicate that the large-scale evolution of convective echo top height increases abruptly near the onset of MJO convective outbreak.
- Local profiles of zonal wind, temperature, and humidity are consistent with large-scale fields observed via satellite or as depicted in reanalysis.
- Large-scale anomalies of 150 hPa zonal wind and 300 hPa temperature exist prior to convective onset and move into the Indian Ocean from the west. Their propagation speeds and relative positions indicate that they are part of a Kelvin wave structure, which evolves into part of a forced response to heating once over the Indian Ocean.
- No such humidity anomalies predate convection. They are likely caused by some combination of cloud and advective moistening.
- Widespread convective events associated with an MJO do not begin over the Indian Ocean until a divergent anomaly aloft approaches the area. For the AMIE cases, the divergent anomalies propagate eastward as a Kelvin wave.

A Proposed Mechanism for MJO Convective Onset

Stratiform clouds are the dominant type of precipitating cloud present during convectively active MJO periods. They provide upper-tropospheric heating, making the total diabatic heating deep so that a Gill (1980) type Kelvin-Rossby response can develop.

Upward (downward) motion in the upper troposphere enhanced (suppresses) stratiform development. During periods with large-scale divergent anomalies aloft, large stratiform regions will flourish, and an MJO convective event can become established.



[1]Powell, S. W., and R. A. Houze, Jr. (2014), *J. Geophys. Res. Atmos.*, submitted.
[2]Powell, S. W., and R. A. Houze, Jr. (2013), *J. Geophys. Res. Atmos.*, **118**, 11979-11995, doi:10.1002/2013JD020421.

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