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 (1989), have indicated that upper-level negative velocity potential anomalies (divergence aloft) coincide with convective outbreaks.
- Velocity potential anomalies are tracked during AMIE by Gottschalk 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

- 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.
- 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.
- 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 regions observed by S-POLAR.
S-POLAR: 1-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

3.1 Evolution of Echo Top Height Observed by TRMM

Three convectively active MJO events

Top: Normalized probability of detection of 2D DBZ echo top for convective echoes composited between 270, 270, 270, and 270-280-290 day variability in mass 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 RBZ.

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

3.2 Gan Rawinsonde Profiles Consistent with Large-Scale

- Zonal Wind
- Temperature
- Humidity

3.3 Evolution of Convective Echoes Prior to Outbreak

Right: Histograms of 20 dBZ echo top Ensemble composite of TRMM detected convection for December and November 2011 MJO events. Large-stratiform region is defined from 25 to 30 days. When the echo top height signifies convection, Prior to this, this indicates the height at which convection has propagated. Below: No cutoff for details. In general, convective echoes provide substantial modulation at all levels and stratiform echoes provide slight modulation.

About a week before MJO convective outbreak over the Indian Ocean, stratiform echo tops increase in number and size but not in upper-level moistening. This primarily happens for broad hydrometers and is isolated to the convective regions that later become the upper troposphere.

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

4.1 150 hPa Zonal Wind and 300 hPa Temperature

Left: Hovmöller for 150 hPa u anomaly. Right: Hovmöller for 300 hPa T anomaly. Extreme propagating anomalies of zonal wind and temperature exist within Indian Ocean. Convective outbreak does not begin until divergent anomaly appears at 150 hPa. Propagation speed and relationship between anomalies of u and T conforms 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.

4.2 300 hPa Specific Humidity and Relative Humidity

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

4.3 850 hPa Zonal Wind and Temperature

Left: Hovmöller for 850 hPa u anomaly. Right: Hovmöller for 300 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. These large tropospheric anomalies are likely to cause low-level wind anomalies observed near and east of Gan, representing anomalous large-scale convergence associated with widespread convection. No such signal is observed in the temperature field.

5. Plan Views of Propagating Zonal Wind and Temperature Anomalies

5.1 150 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.

5.2 300 hPa Specific Humidity and Relative Humidity

6. Conclusions

- S-POLAR observations of convective echo top height are consistent with TRMM observations, which indicate that the large-scale evolution of convective echo top height accelerates prior to 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 the MJO do not begin over the Indian Ocean until a divergent anomaly aloft approaches this 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 enhances (suppresses) stratiform development. During periods with large-scale divergent anomalies aloft, large stratiform regions will flourish, and at MJO convective events can become established.

Enhanced Convection

Suppressed Convection

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The Role of Upper-Tropospheric Dynamics in MJO Convective Onset

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