Radar-Based and Large-Scale Views of Convection and Tropospheric Humidity during DYNAMO/AMIE

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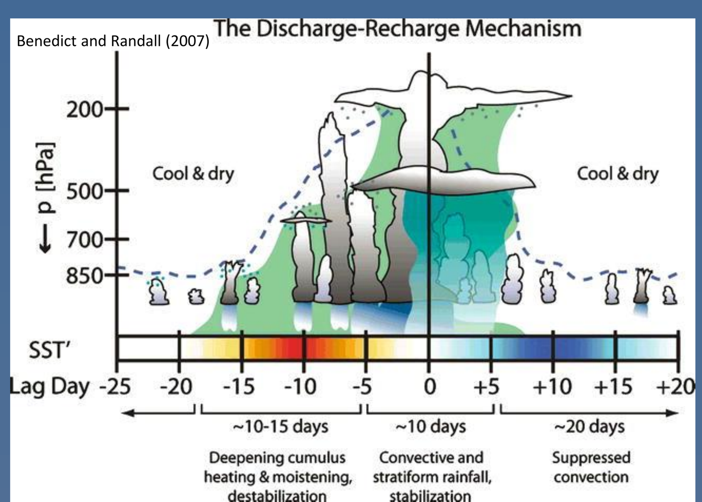
1. Introduction

- One goal of DYNAMO/AMIE is to test hypotheses regarding MJO onset and propagation.

- Knutson and Weickmann (1987) first show evidence that an equatorial Kelvin wave response to one convective event circumnavigates in the upper-troposphere as a velocity potential anomaly, exciting the next event.

- Bladé and Hartmann (1993) point out that no explanation exists for how convection is affected by upper-tropospheric dynamics. They propose a *"discharge-recharge"* mechanism: Convection and humidity feedback onto each other, thus allowing humidity to slowly build vertically as convection becomes gradually taller in the 10 to 20 days prior to a convective event.



2. Objectives

- Examine the evolution of humidity and convection prior to onset of three MJO events over the central Indian Ocean during DYNAMO/AMIE.

- Compare the evolution of convective echoes observed over Addu Atoll, the site of the ground-based radar, S-PolKa, during DYNAMO/AMIE, to their evolution over a larger domain.

- Compare the structure of upper-tropospheric zonal wind, temperature, and humidity anomalies near Addu Atoll to the same anomalies in the large-scale environment.

- Document whether the anomalies propagated into the region prior to MJO convective onset or were formed during by deep convection over the Indian Ocean.

- Explore the three-dimensional structure and propagation of the anomalies leading up to MJO convective onset.

3. Data

- S-PolKa: NCAR's combined S-band and Ka-band dual-polarimetric radar system, which was located in Addu City, Maldives.

- Rawinsondes launched from the nearby ARM Mobile Facility of the Department of Energy provided upper-level wind, temperature, and humidity information.

- TRMM: Reflectivity data from the precipitation radar aboard the Tropical Rainfall Measuring Mission is used for comparing the evolution of clouds over a large domain against S-PolKa data, which is limited to a small area with 150 km of the radar.

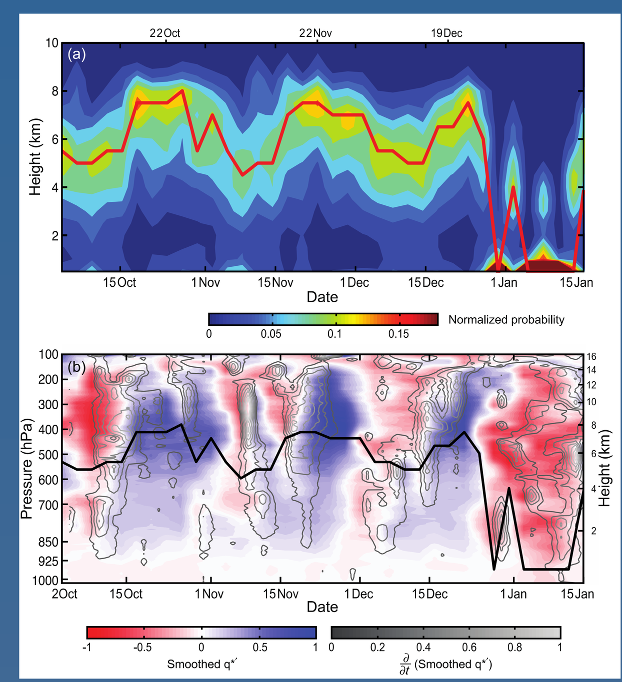
- ERA-Interim (ERA-I) reanalysis is used to compare the time series of variables measured via sonde with time series of those variables over a larger domain. Though not shown, the ERA-I humidity field matches the humidity field remotely observed by the Atmospheric Infrared Sounder (AIRS).

4. Radar and Rawinsonde Observations[1]

Rapid Humidification and Echo Top Height Increase

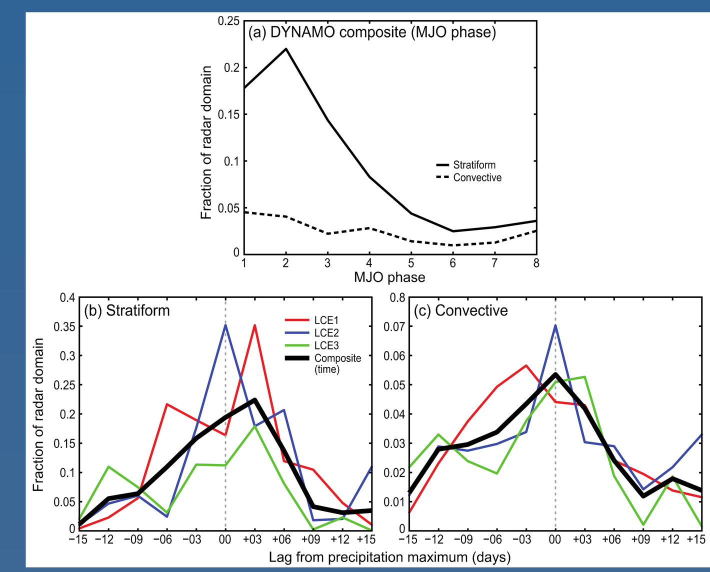
a) Time series of PDF for 20 dBZ echo top heights smoothed into three-day intervals. Red line follows the modal distribution. Dates along top axis represents days of filtered precipitation maximum for each event.

b) Time series of q'' smoothed to three-day intervals. Black line is the same as red line in (a). Contours are Eulerian derivative of q''.



- Rapid increases (3 to 7 days) in echo top heights observed at beginning of convective events. Humidification of troposphere above 850 hPa occurs over no longer than 10 days during any of the convective events. This time scale is much shorter than that prescribed by "discharge-recharge".

Rapid Increase in Areal Coverage of Precipitation Echoes



a) Fractional coverage of S-PolKa domain with detectable stratiform and convective precipitating echo separated by Wheeler and Hendon (2004) MJO phase.

b) Same as a but for stratiform echoes over the three events by date relative to a filtered maximum in rainfall.

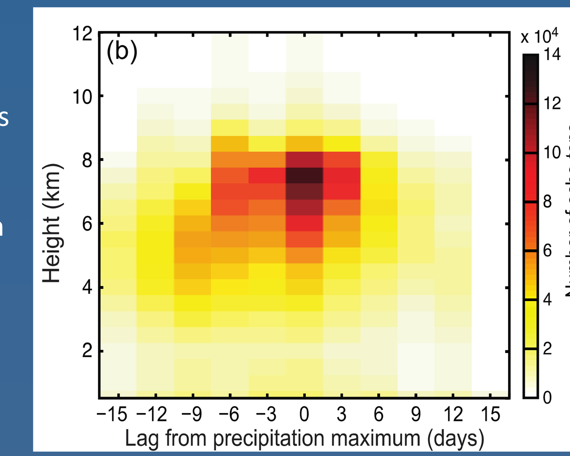
c) Same as b but for convective echoes.

(LCE = Large-scale convective event)

- Areal coverage of convective and stratiform echoes increases sharply over less than a week (colored lines in b and c).
- Compositing by phase (a) cannot capture the rapid increase in amount of precipitating echo because a single phase may last various lengths of time from case to case.
- The composite of just three convective events (bold, black line in b and c) shows an unrealistic increase in echo area occurring over about two weeks, which is consistent with "discharge-recharge".
- The importance of examining each unique MJO case individually is highlighted here. We cannot make conclusions about the dynamics of any MJO event based on a composite of several events.

Convection Precedes Humidification

(Right): Histogram of echo top heights as a function of day relative to filtered precipitation maximum during three DYNAMO MJO events. The number of convective echo tops below 6 km increases before the convection deepens. Thus, shallower convective cells widen and/or increase in number prior to the increase in convective depth and stratiform development.



(Below): Lagged cross-correlation coefficients between precipitation echo areal coverage and humidity at various levels. Generally, precipitating echoes lead humidification at short lag times.

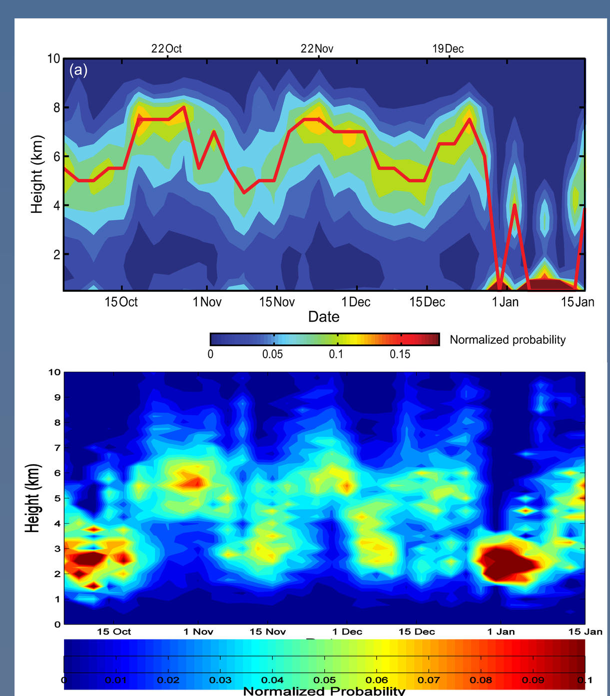
Table 3. Maximum Lagged Cross-Correlation Coefficients (With Lag in Hours in Parentheses) Between Convective/Stratiform Areal Coverage and Unfiltered, Unsmoothed Specific Humidity Anomalies for 1 October to 15 January Using Various Smoothing Periods[a]

		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).

5. Comparing Field Observations with Large-Scale Data

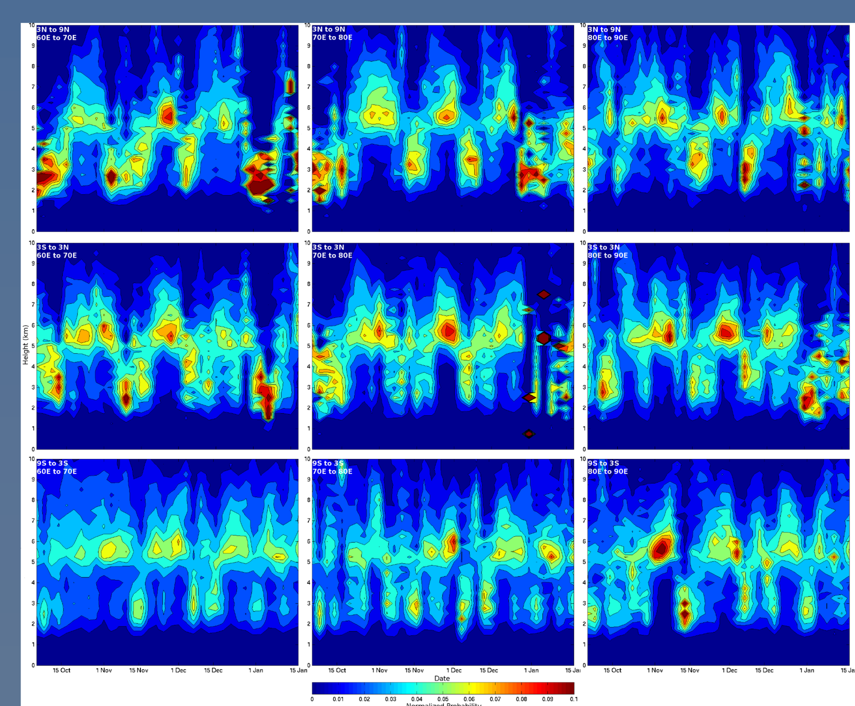
Large-Scale Evolution of Precipitating Echoes Matches S-PolKa; Southern Hemisphere has ITCZ



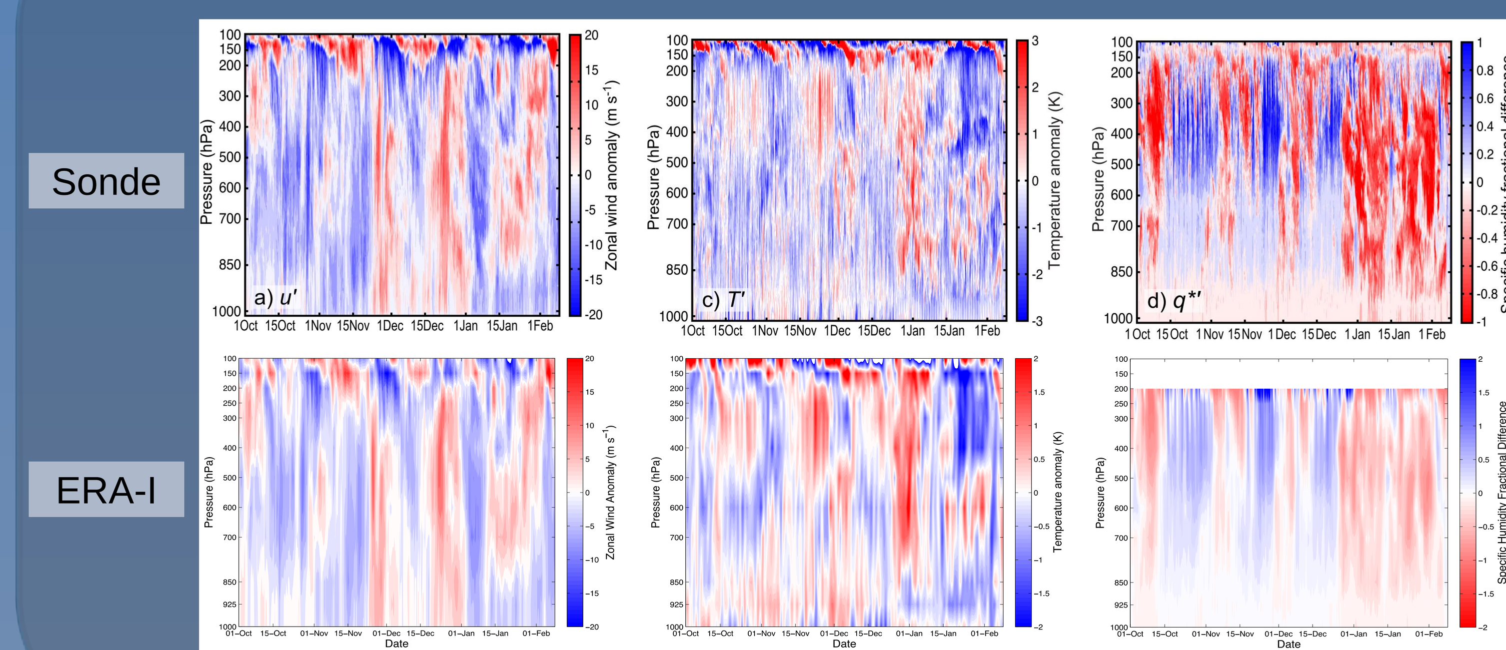
(Top, left): S-PolKa 20 dBZ echo top height time series for convective echoes.

(Bottom, left): Same as top, but using TRMM data between 0°N and 9°N and 68°E and 78°E.

(Right): Same as bottom left but for stratiform and convective echoes over various labeled regions.



Large-Scale Dynamic and Thermodynamic Fields Match Sonde Observations



Top row: Time series of zonal wind, temperature, and fractional difference of specific humidity from the mean observed by rawinsondes during AMIE.

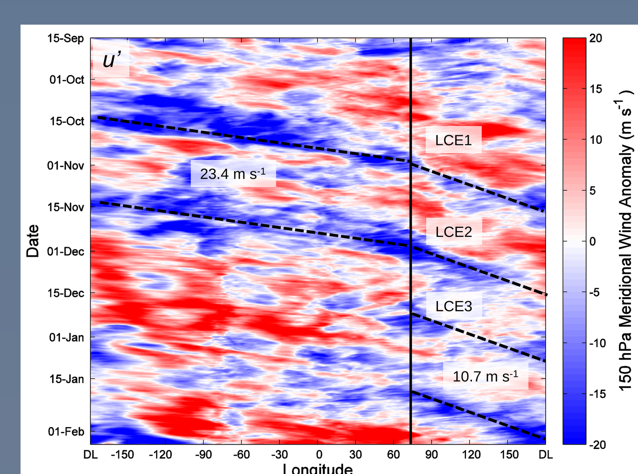
Bottom row: Same variables as top, but compiled using ERA-I between 3°S and 3°N and 68°E and 78°E.

6. Propagation and Structure of Upper-tropospheric Anomalies

Kelvin Wave Signal in Zonal Wind Anomalies

ERA-Interim reanalysis is used to extend rawinsonde dataset to evaluate three-dimensional wind field. Shown is the 150 hPa u'.

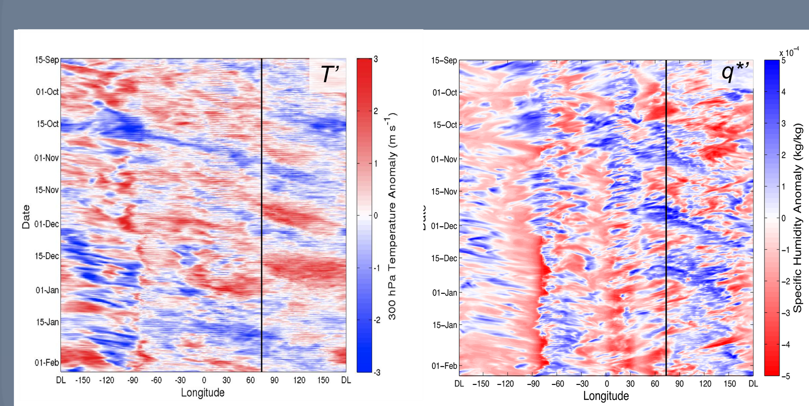
Black dashed lines correspond to phase speed of Kelvin wave, which is identifiable objectively and subjectively in 2-dimensional analysis of wind field.



- At Addu, an easterly anomaly precedes a westerly anomaly during each convective event. No such feature (of opposite sign) is observed to propagate from the west at lower levels.

- The Kelvin wave appears to circumnavigate and excite convective events in October and November. Whether the signal continues to circumnavigate is unclear in the present analysis. Regardless of the source of the Kelvin mode, a convective event does not begin at Addu until the divergent upper-level anomaly approaches from the west.

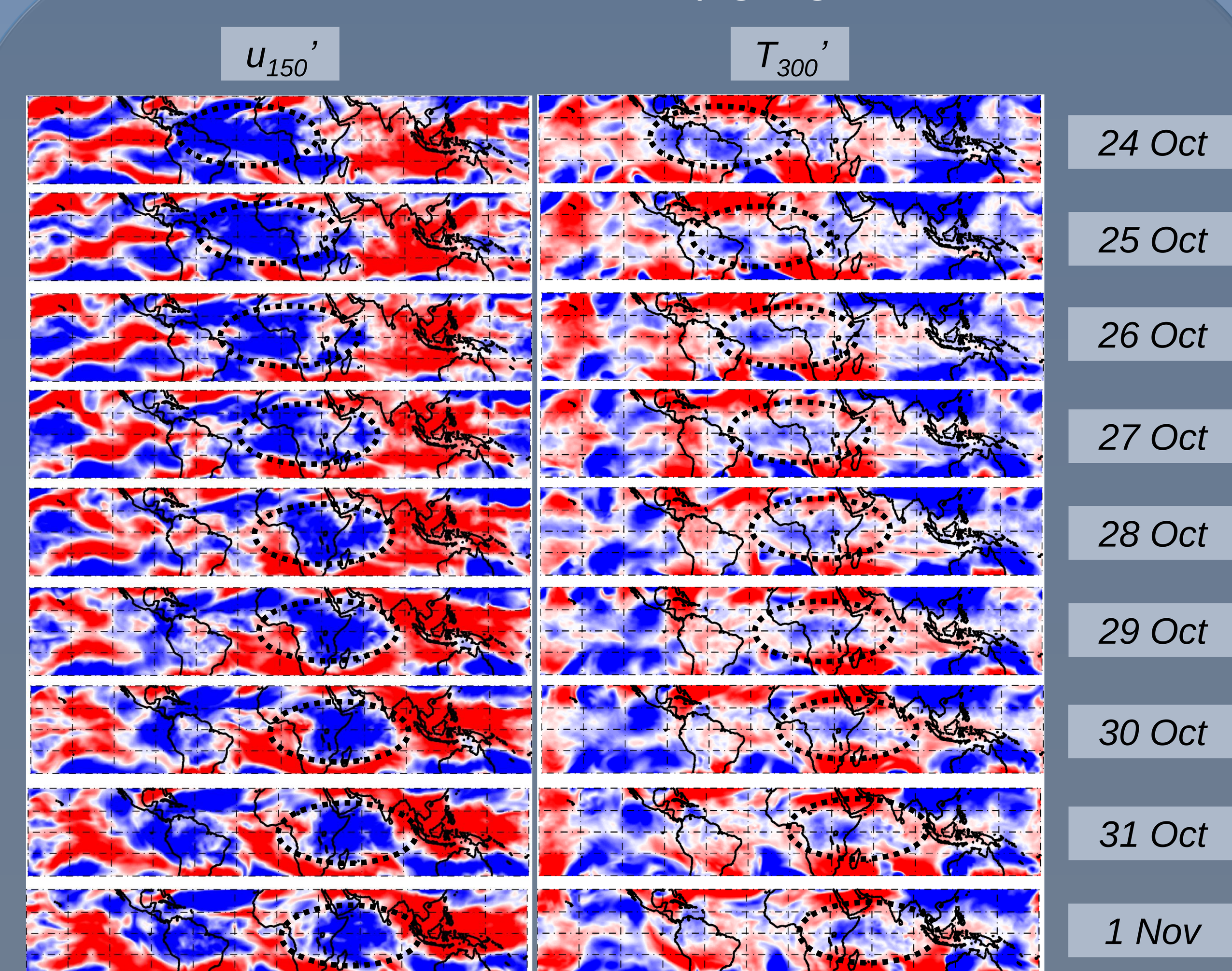
Temperature Anomalies Also Predate Convection; Humidity Anomalies Do Not



300 hPa temperature anomalies are shown to propagate into the Indian Ocean from the west as well and are in quadrature with 150 hPa u'.

300 hPa humidity anomalies develop where the widespread convection forms and do not propagate into the region, further supporting the claim that convection causes the moisture anomalies aloft.

Plan Views of Eastward Propagating Anomalies



Time series of plan views of u_{150}' and T_{300}' from 24 October to 1 November, corresponding to the end of a convectively active period near the DYNAMO/AMIE field site. Dashed black circles highlight eastward propagating easterly wind anomalies and negative temperature anomalies, respectively.

Anomalies appear to be centered around equator. Anomalies of temperature very closely follow the equator. Because they propagate eastward, both are indicative that the anomalies are related to an equatorial Kelvin wave.

7. Conclusions/Future Work

- Convective echoes and positive humidity anomalies increase in height over 3-7 days prior to onset of widespread, organized convection. "Discharge-recharge" is not the cause of onset of the large-scale convective events observed during DYNAMO/AMIE.

- Compositing the three events together gives a result that appears to support "discharge-recharge", though examination of each event individually does not. We stress the importance of examining MJO events on a case-by-case basis for making conclusions about the dynamics responsible for MJO convective onset.

- Radar and rawinsonde observations obtained in Addu City match observations from TRMM and reanalysis fields of zonal wind, temperature, and humidity over a large domain in the Indian Ocean; thus, the 30-day variability seen in field observations is consistent with what is observed elsewhere.

- Upper-tropospheric zonal wind and temperature anomalies propagate into the region of MJO convective onset from the west. Humidity anomalies do not.

- MJO-related convection does not occur until divergent wind anomalies near the tropopause and upper-tropospheric positive temperature anomalies reach the central Indian Ocean. Future studies will investigate the potential role(s) of these anomalies in enhancing or suppressing widespread convection.

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