Tropospheric Humidification and Cloud Microphysical Structure Observed over the Indian Ocean during AMIE

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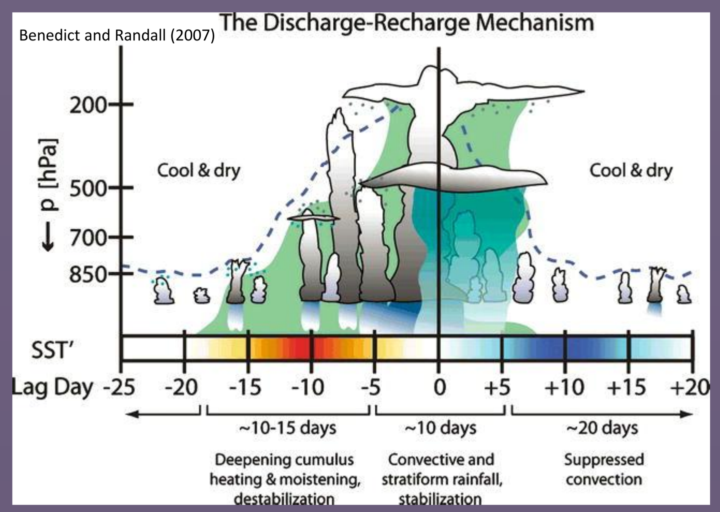
1. Introduction

- Two hypotheses concerning onset of convection in association with the MJO are examined.

- Knutson and Weickmann (1987) 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) 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.



- Efforts to model the MJO require adequate representation of cloud microphysics and dynamics. Convection is linked to the large-scale circulation via latent heating by cumulus clouds and large stratiform regions, thus any existing relationship between the cloud population and environmental humidity must be determined. Additionally, microphysical properties of the cloud population must be examined in order to anchor numerical simulations to such observations.

2. Objectives

- Describe the structure and organization of convection prior to, during , and after a convective outbreak associated with the MJO.

- Investigate the relationship between convective clouds, humidification of the troposphere, and MJO onset.

- Explore potential impacts of large-scale equatorial modes on MJO-related convection over the Indian Ocean.

- Establish framework for examining microphysical structure of clouds detected by cloud and precipitation radars.

3. Instrumentation

S-PolKa: NCAR dual-wavelength, dual-polarimeteric S/Ka-band (precipitation) radar. High-elevation scans were conducted over a sector that included the azimuth over KAZR, about 10 km to the southeast.

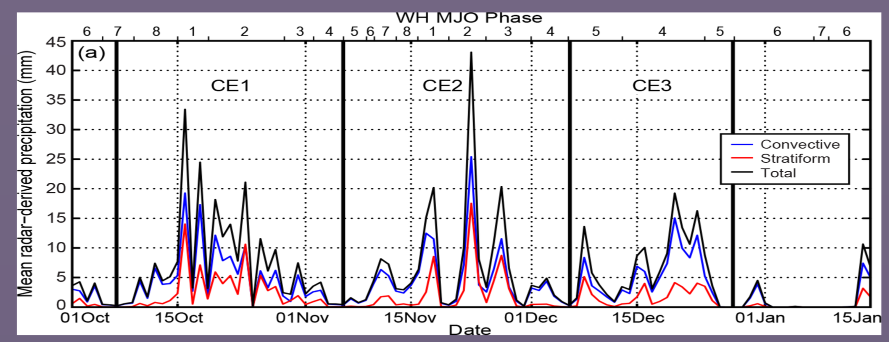
KAZR: Ka-band ARM Zenith Radar: Doppler cloud radar capable of detecting non-precipitating clouds with small hydrometeors.

Rawinsondes: Soundings were launched every 3 hours from Gan Island during AMIE and measured profiles of wind, temperature, and humidity.

4. Radar and Rawinsonde Observations

Precipitation Time Series

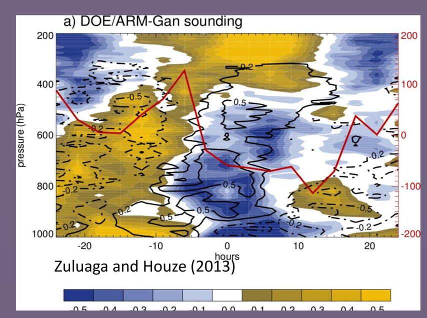
Three MJO-related convective events were observed. Generally, convectively generated rainfall contributed to about half of total during widespread stratiform events.



December event not as well-sampled; deepest convection formed east of S-PolKa. Intense squall lines with smaller stratiform areas were favored in December.

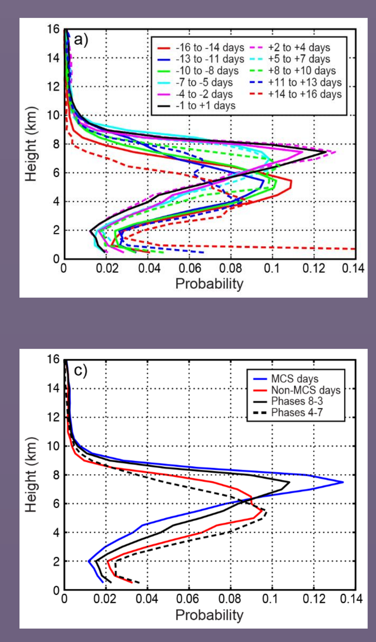
High-frequency variability

Variability in precipitation on 2-day and 4- to 6-day time scales is observed in October and November, respectively, and has been attributed to inertio-gravity and mixed Rossby-gravity or equatorial Rossby waves.



The composite structure of temperature resembles that of a westward propagating inertio-gravity wave. Mixed-Rossby gravity modes are seen in reanalysis (not shown).

S-PolKa Echo-top Heights

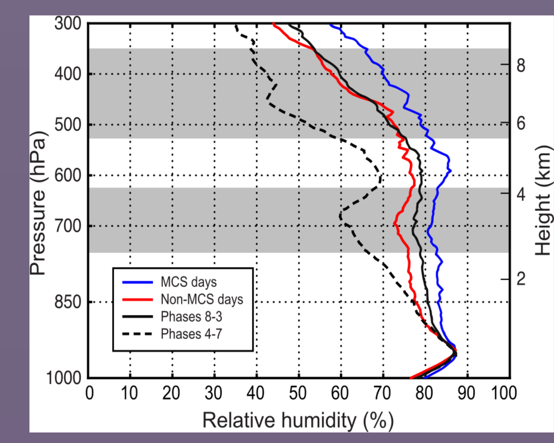


a) Normalized PDFs of echo-top heights for 3-day intervals. Modal distribution of echo-top heights is highest (~ 7.5 km) near Day 0.

c) Normalized PDFs of echo-top heights to examine the potential effect of equatorial waves on cloud depth during an active MJO event.

MCS (Non-MCS) Days: Precipitation on preceding and following days less (more). PDF during MCS days is significantly different (p = 0.05) than during Non-MCS days (similar to suppressed WH MJO phases 4-7.

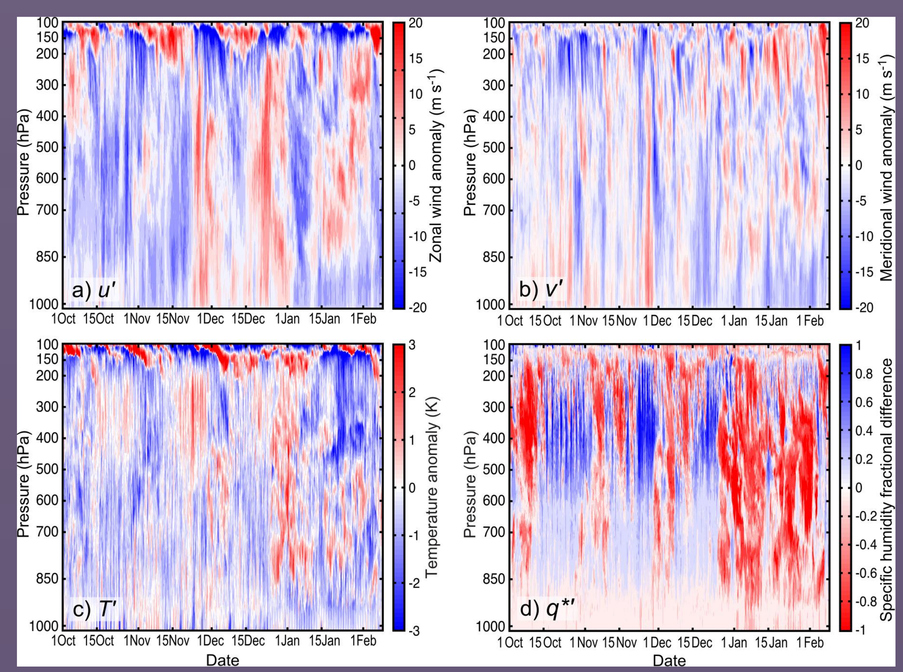
Humidity on MCS Days and Non-MCS Days



- Similar humidity on both MCS days and non-MCS days (>70% below 500 hPa).
- Although echo top PDF for Non-MCS Days and suppressed WH MJO phases are very similar, differences in humidity during these days are statistically significant (p = 0.05) at the levels shaded in gray.
- Dynamical support , which probably varies dependent on equatorial wave modes, is more important than environment humidity for developing deep convection.

AMIE Rawinsonde Time Series

Time series of u', v', T', and q'' are shown below. Anomalies are computed relative to the time mean at each pressure level (binned to 5 hPa intervals) for the period shown. q'' is the fractional difference from the time mean of specific humidity.



-26-30 day variability is seen in u' and T' at 150 hPa. Deep westerly anomalies observed in late November and mid-to-late December.

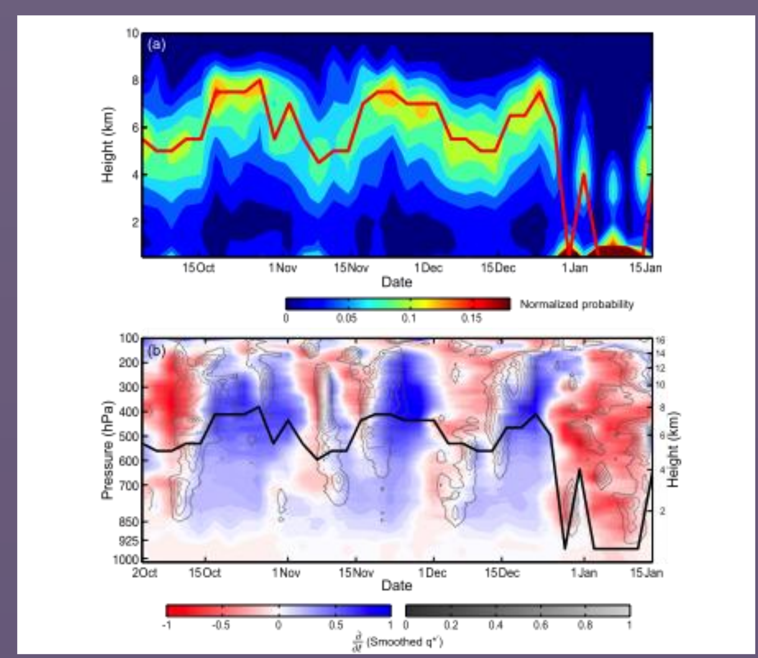
- Warm and moist anomalies between 500 and 200 hPa correspond with convective events.

- Dry, suppressed conditions in January.

Echo-top Heights and Humidification

a) Time series of PDF for 20 dBZ echo-top heights smoothed into three-day intervals. Red line follows the modal distribution.

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''.



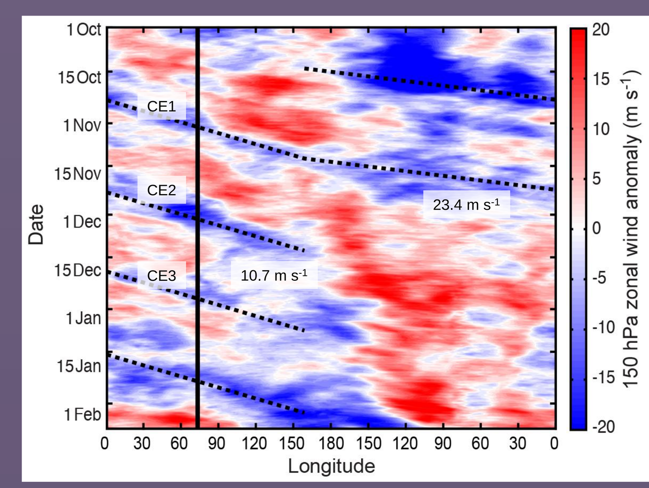
- Rapid increase in convective echo-top heights occurs at beginning of October and November convective events. Smaller increase observed more gradually in December. The period of moistening prior to a convective event lasts no more than 10 days. While episodes of moistening may occur even earlier (November and December), drying occurs before moistening begins again. This is clearly inconsistent with the "discharge-recharge" mechanism.

- The direct relationship between clouds and humidity is inconclusive. For three convective events, the increase in convective echo-top heights occurred after (October), before (November), and during (December) the greatest increase in moisture through a deep layer.

5. Equatorial Kelvin Wave

ERA-Interim reanalysis is used to extend rawinsonde dataset to evaluate three-dimensional wind field. Below 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.

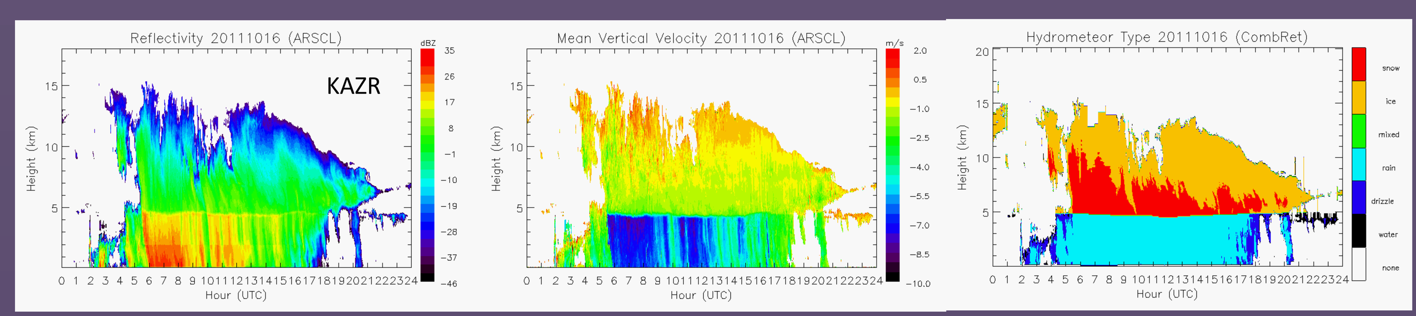


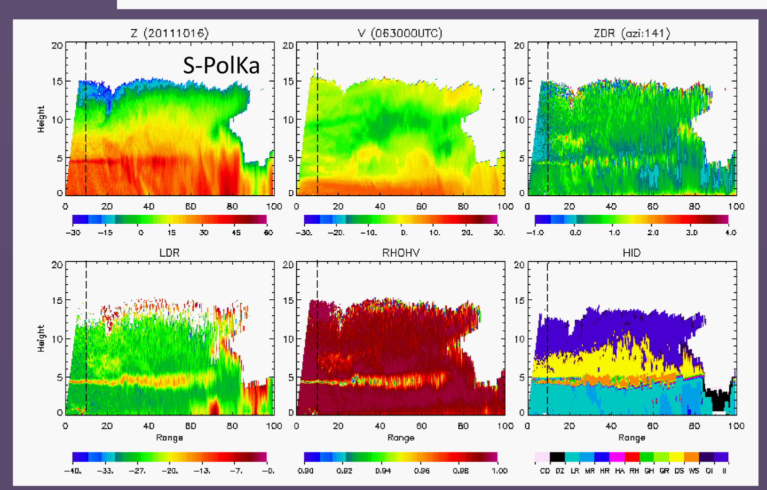
- At Addu, an easterly anomaly precedes a westerly anomaly during each convective event. No such feature (of opposite sign) is observed to propagate from the west at lower levels. We propose that the large-scale changes in divergence and subsidence in the upper-troposphere (down to 300 hPa) caused by the Kelvin wave modulates the convection on MJO-related timescales.

- 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.

6. Cloud Microphysics derived from KAZR and S-PolKa

Hydrometeor Classification with KAZR and S-PolKa





- KAZR/lidar product (PNNL) provides vertical information about hydrometeor species in addition to reflectivity and vertical velocity available from KAZR.

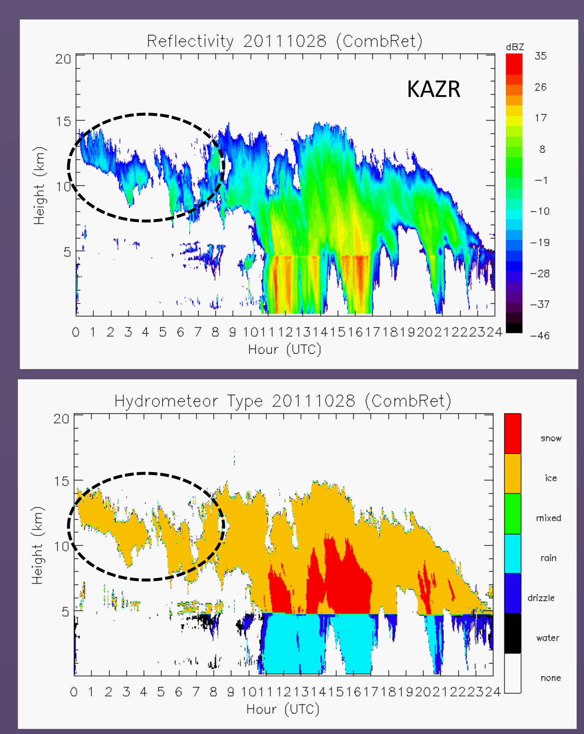
- Does not include the mixed phase, which, as seen in S-PolKa data, is a prominent classification near the melting level.

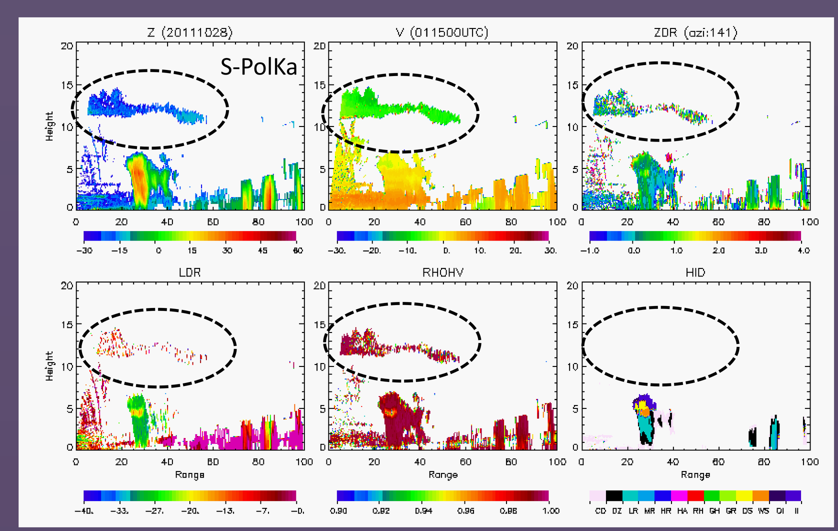
- Comparison with S-PolKa also shows slightly deeper "snow" for KAZR/lidar.

- S-PolKa data used to put KAZR vertical information within the context of the broader system.

- Vertical velocities from KAZR combined with radial velocities from S-PolKa provide a more complete picture of the kinematics.

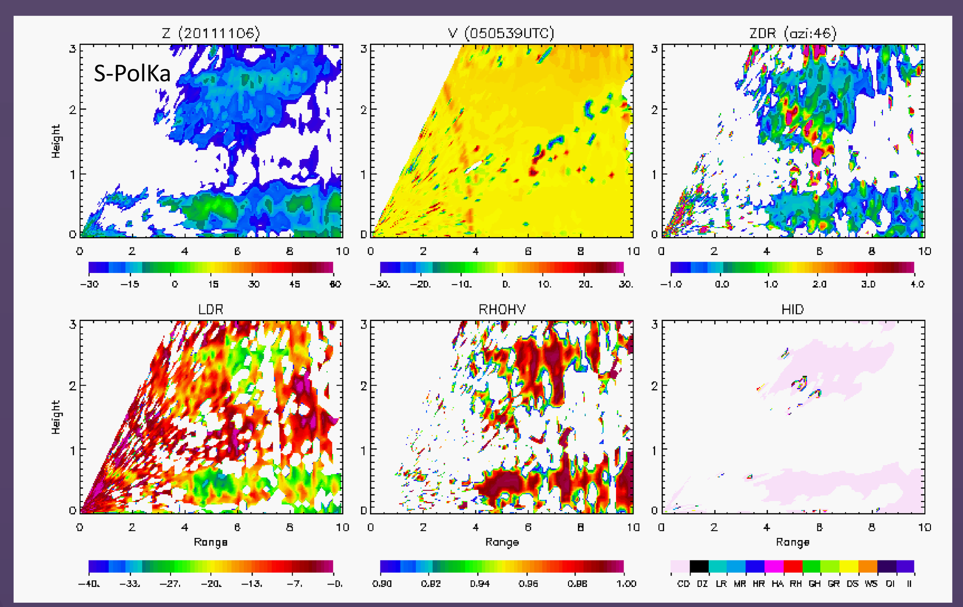
Thin Anvils





Thin anvils more clearly observed with KAZR, but, although S-PolKa polarimetric variables show similar echo, the particle identification is not picking up on the ice as the KAZR/lidar product had classified

Shallow Non-precipitating Echo



Feng et al. (2013) noted that when compared to KAZR data, S-PolKa missed a large percentage of the shallow echo, as well as thin anvils. In that study, S-PolKa data was quality controlled using signal-to-noise ratio only, possibly eliminating some real echo, while ground clutter remained. This RHI highlights the utility of the polarimetric variables to help identify developing echo, and, with the KAZR data, to investigate the transition from non-precipitating to precipitating echo.

7. Conclusions/Future Work

These studies highlight our use of the ARM instrumentation during AMIE, along with the additional information provided by the S-PolKa radar, to understand the link between the cloud population and environmental conditions for improved numerical modeling. The following points summarize our results:

- Convective cloud depth is not controlled solely by environmental humidity.
- Rapid (~3-7 day) increase in humidity observed above 850 hPa, which closely corresponds with sharp increase in convective cloud top height. Conclusions using sounding data must be extended to larger-scale with satellite data.
- Convection does not initiate until upper-tropospheric Kelvin anomaly reaches the central Indian Ocean.
- Upper-level support for deep convection and large stratiform regions may be controlled by wave dynamics.
- "Quasi-periodicity" may really only refer to the irregular interval at which upper-level support is present for MJO onset.
- Using the KAZR data within the context of S-PolKa observations provides valuable information about the evolution of the entire cloud population and allows for more detailed descriptions of the kinematic and microphysical properties of both non-precipitating and precipitating clouds. Future work requires improved techniques for isolating weaker echo from S-PolKa and describing the onset of precipitation using the suite of radars available.

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