Mesoscale Organization along Cold Pool Boundaries in Trade-wind Region observed during RICO
Zhujun Li and Paquita Zuidema
zli@rsmas.miami.edu

1 Introduction
Precipitating trade-wind cumuli organized along the cold pool boundaries were observed during Rain in Cumulus over the Ocean (RICO) experiment. The arc-shaped formation of cumuli has previously been thought to occur at the edges of cold pool outflow from previous convection (Snoevers et al. 2009), and are shown separately in Fig. 1. Tompkins’s model study argued cold pools resulting from tropical deep convection could encourage new convection based on buoyancy consideration alone (Tompkins 2001), with the moisture contribution critical. We examine this mechanism for the observed warm-rain convections.

2 Data
We focus on the January 9-24, 2005 time period. January 9, 10 and 13 were disturbed days containing straitflow precipitation (Fugere 2009), and are shown separately in Fig. 1. GOES: GOES-12 satellite channel 1 visible images taken at 1 km every 30 minutes, are used to identify the arc-shaped organization of trade-wind cumuli. S-Pol: Barbuda based NCAR S-Band Polarimetric (S-Pol) radar reflectivities acquired at 0.5° elevation, during surveillance scans every 20 minutes and irregular plan position indicator scans. Shipboard measurements (R/V Seward Johnson (RVSJ)): Soundings report the atmosphere profiles every 4 hours. The air temperature (°C, z=15.5 m), air specific humidity (g/kg, z=13 m), and bulk latent heat flux (W/m²) are collected by NOAA ESRL system (5-min in use). The same system also provides true wind (m/s, measured by sonic anemometer at 14 m and surface rain rate (uncorrected mm/hr, optical rain gauge). Other data include water vapor path (WVP), liquid water path (LWP) derived from microwave radiometer (available in 30-sec), X-band signal-to-noise ratio (SNR) from Barbuda NCAR, vertically-pointing 9.4 GHz radar, and sea surface temperature (SST) from sea snake temperature (°C, z= 0.05 m).

3 Results
The immediate impact of all 37 rain events on surface air properties is summarized in Fig. 1, with the 17 shallow-convection-only cases highlighted. The temperature decrease in Fig. 1 is from pre-rain event to the minimum temperature. The decrease in surface humidity and θe as temperature decreases (Fig. 1a, 1b), indicates the surface temperature depression is not only caused by sub-cloud evaporation of precipitation, but also associated with the precipitation driven downdrafts. It is clear that, as the deep convection, the shallow convection is as well capable of bringing down drier air with negative buoyancy. The increase of surface wind speed around the recovery is shown in Fig. 1c and 1d. All but 1 event are associated with arc cloud around cloud free pool, of which Fig. 2 from January 11 is an example.

The ship encountered the precipitating clouds from the west side (Fig. 2 and 4b), reporting immediate drop in temperature, but continuity in relative humidity (Fig. 4a). The surface air on the west side of the convection is distinguished from the air below convection by a difference of 8 K in θe, implying different sources of air in these two regions. The cold air below convection was originated from the low θe level above (Fig. 3d), while the air on the west side can be interpreted as the residual of the gust that had been cooled and moistened by previous convection then pushed to the west by the mean easterly winds (Tompkins 2001). In addition, we note the new θe minimum at 1-2 km in the 12UTC sounding.

4 Conclusions
1) Shallow warm-rain convection is able to produce significant precipitation which generates downdrafts that cause the depression in temperature and humidity at the surface.
2) Cool but moist air spurs precipitating convection on the west side of the cold pool, while warm but dry air spawns non-precipitating clouds on the east side.
3) Consistent with Tompkins’s model mechanism, buoyancy generated by positive moisture anomalies appears necessary for the development of deeper convection.

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References

Fig. 1. a) Maximum specific humidity decrease, b) equivalent potential temperature decrease, and c) wind speed increase, all as a function of the maximum temperature drop, for all 37 rain events, with undisturbed and disturbed days shown as closed and open circles, respectively. d) Differences between the Bowen ratio, sensible and latent heat fluxes from before each rain event to the post-precipitation. The color indicates qualitatively the amount of latent heating needed to maintain the Bowen ratio at a constant value, with red indicating an increase, and blue a decrease.

Fig. 2. Left panel January 11 GOES-12 1145 UTC [0745 LT] visible image at 1 km resolution. Mesoscale boxes indicate approximate region highlighted in the top four right-hand panels: GOES-12 visible radiances overlaid with the 5-km radar reflectivities, shown at 1215, 1215, 1245, and 1315 UTC. Red line indicates the ship’s track, with red circle indicating the ship, and white dashed lines at 18:15 and 50° W. Bottom right-hand panel: Vertically-pointing shipboard X-band radar data from 15UTC to 1115UTC. Dashed lines indicate approximate trajectory of the 12UTC sounding.

Fig. 3. a)0-555/05 soundings report the atmosphere profiles every 4 hours. The air temperature (°C, z=15.5 m), air specific humidity (g/kg, z=13 m), and bulk latent heat flux (W/m²) are collected by NOAA ESRL system (5-min in use). The same system also provides true wind (m/s, measured by sonic anemometer at 14 m and surface rain rate (uncorrected mm/hr, optical rain gauge). Other data include water vapor path (WVP), liquid water path (LWP) derived from microwave radiometer (available in 30-sec), X-band signal-to-noise ratio (SNR) from Barbuda NCAR, vertically-pointing 9.4 GHz radar, and sea surface temperature (SST) from sea snake temperature (°C, z= 0.05 m).

Fig. 4. a) Maximum specific humidity decrease, b) equivalent potential temperature decrease, and c) wind speed increase, all as a function of the maximum temperature drop, for all 37 rain events, with undisturbed and disturbed days shown as closed and open circles, respectively. d) Differences between the Bowen ratio, sensible and latent heat fluxes from before each rain event to the post-precipitation. The color indicates qualitatively the amount of latent heating needed to maintain the Bowen ratio at a constant value, with red indicating an increase, and blue a decrease.

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From 12:30 to 13:45 UTC (8:30-9:45 LT), the ship was crossing the post-cold pool area from west to east, with the air drying and warming during the travel (Fig. 4a). This area was undergoing the recovery, with the temperature on the east side fully recovered by 13:45 UTC, and the west side just started to restore its properties. Tompkins (2001) argued the recovery of surface layer can be accomplished by the warm and unsaturated environmental air from upper level entraining down to the surface, enhancing the surface temperature and buoyancy (Fig. 4a and 4d). New clouds are generated in the recovered region, as indicated by the high LWP in Fig. 4b, but do not precipitate. The newly-established inversion (dB/dz > 0, Fig. 3d) may have also helped discourage the later convection from penetrating above 3 km. Because cloud development is typically more significant on the west side of the cold pool than the east side within satellite imagery (Fig. 2), we believe this is a representative case.

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