The Impact of Laterally-entrained Midlevel Dry Air on the Establishment of Persistent Deep Convection in Tropical Disturbances

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1. Introduction

- Wang (2014) examined moisture budget in deep convection during formation of Fey (2008)
  - Deep convection is a net moisture sink in the lower and middle troposphere
  - Cumulus congestus is a net moisture source in the lower and middle troposphere
  - Moistening by cumulus congestus acts to offset moisture sink of deep convection allowing for deep convection to persist
  - Persistent deep convection spins up vortex
- Dry Air Inflow Pathways (DAIPs)
  - Layer of midlevel dry air characterized by low directional shear (Fig. 1, orange shading)
  - Typically located below a layer of moister upper-level convective outflow
  - Associated with midlevel vortex drawing dry air from the environment (Fig. 2)

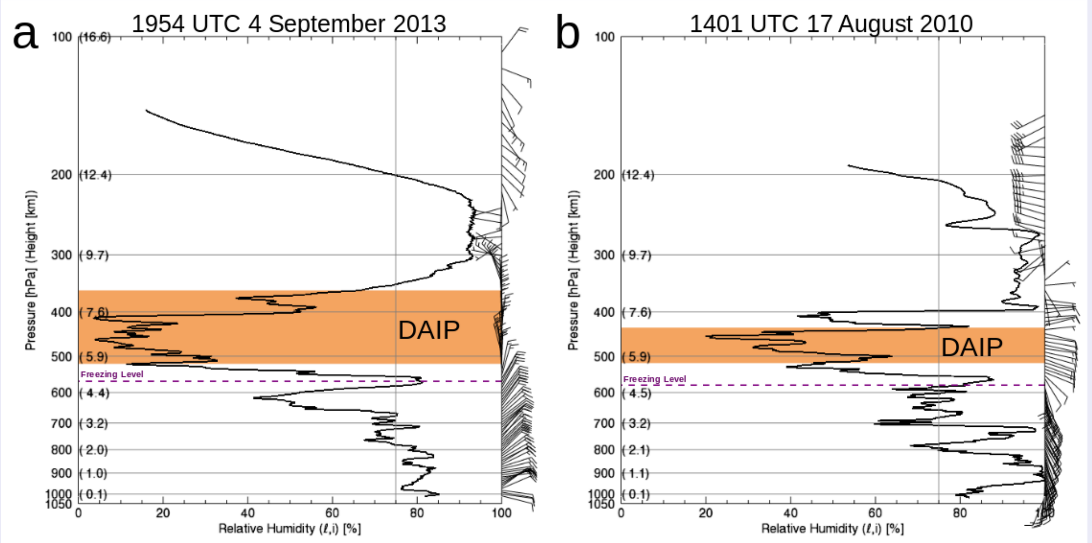

Fig. 1. Profiles of relative humidity and comoving winds calculated from dropsondes released (a) in the pre-Gabrielle (2013) disturbance and (b) in a nondeveloping tropical disturbance designated P27L (2010). Relative humidity is calculated with respect to ice above the freezing level.

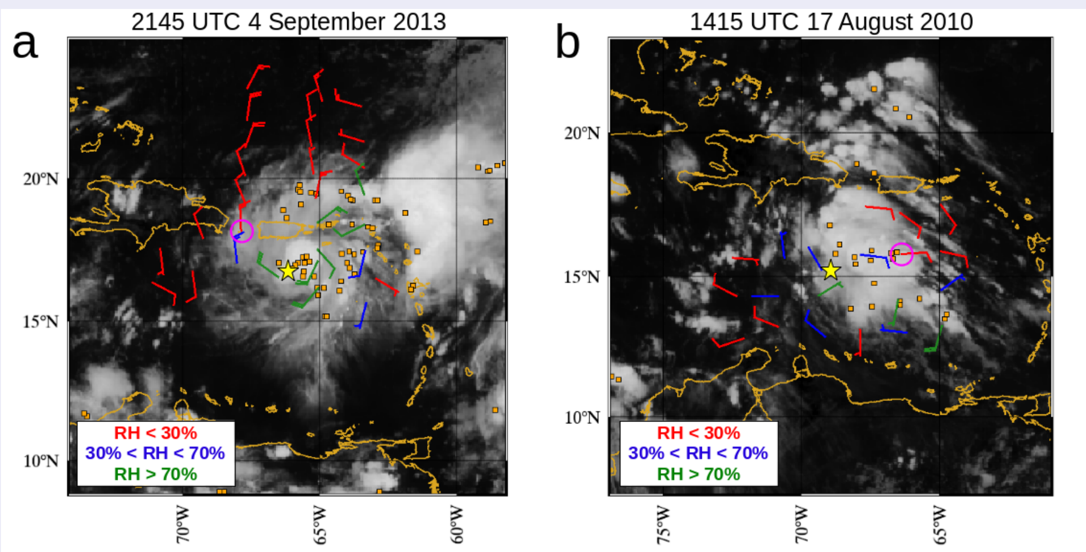

Fig. 2. Infrared satellite images of (a) the pre-Gabrielle (2013) disturbance and (b) the nondeveloping P27L (2010) disturbance The wind barbs indicate the comoving wind at the level with the lowest relative humidity between the freezing level and 300 hPa. The orange squares indicate tropical overshooting tops within the last 3 h (Monette 2013) and the yellow stars indicate the 700-hPa pouch positions. The locations of the soundings in Fig. 1 are indicated by the magenta circles.

2. Hypotheses

- DAIPs inhibit the establishment of persistent deep convection by offsetting the midlevel convective moistening with dry air advection (Fig. 3).
- Dry air that is imported at a lower altitude or via a stronger wind is more detrimental to the establishment of persistent deep convection than dry air imported at a higher level or via a weaker wind.

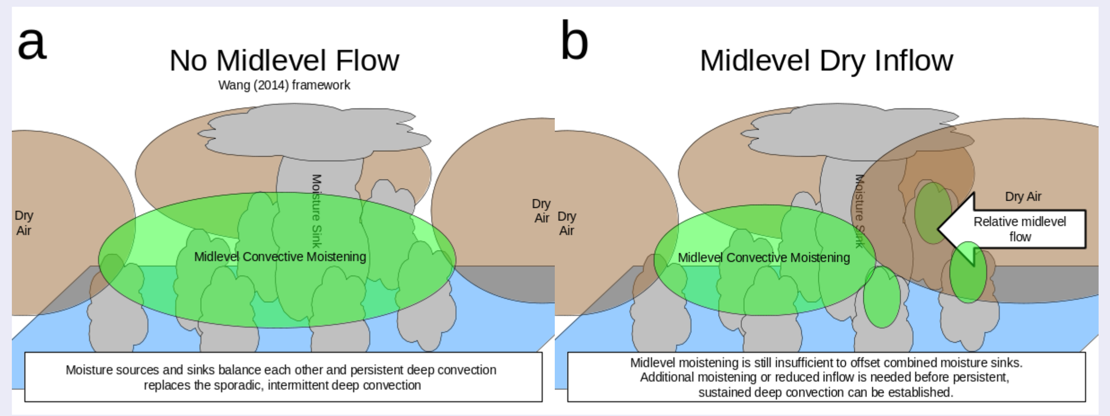

Fig. 3. Schematic representations of a convectively active tropical disturbance (a) without midlevel inflow and (b) with midlevel inflow.

3. Convective Persistence

- Since the DAIP upsets the moisture balance proposed by Wang (2014), we expect the deep convection will collapse faster as moisture is depleted (as per Fig. 3b)
- Deep convection coverage time series (Fig. 4) suggest this may be occurring when a DAIP can draw dry air into the active deep convection region
  - pre-Gabrielle (Figs. 1a, 2a, 4a): Deep convection is within midlevel vortex so DAIP is not transporting dry air into active deep convective region
  - P27L (Figs. 1b, 2b, 4b): Deep convection is northeast of midlevel vortex so DAIP transports dry air directly into active deep convection region

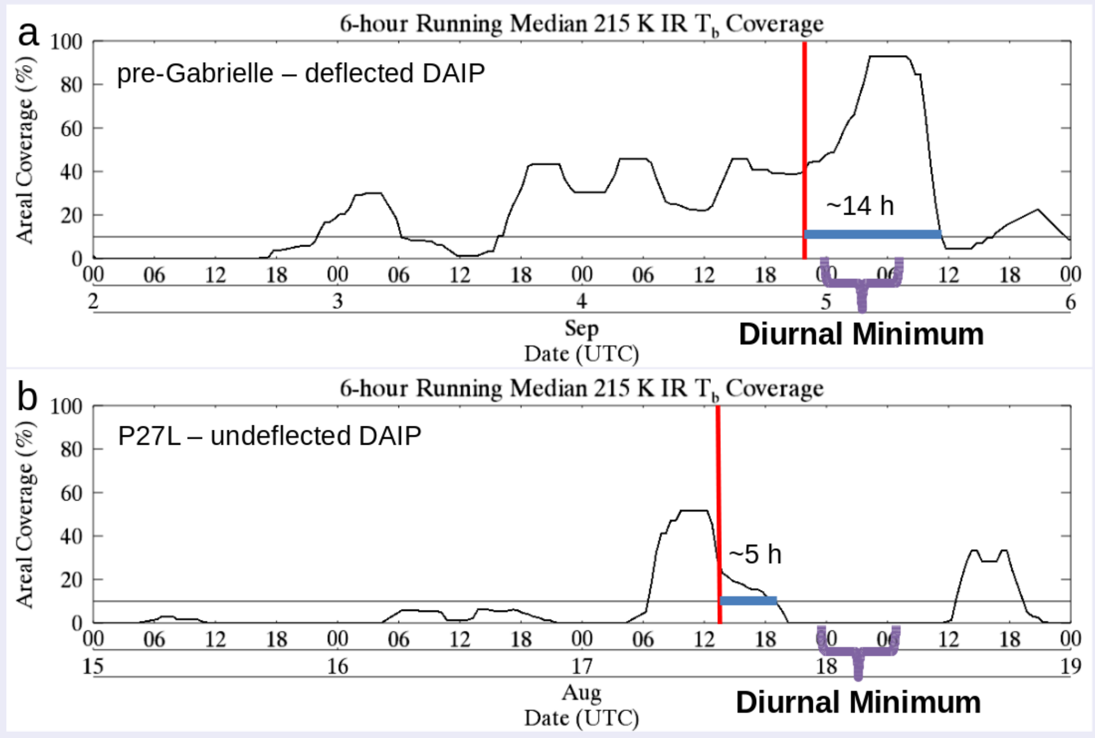

Fig. 4. Time series of areal coverage of infrared brightness temperatures colder than 215 K over a 100-km radius circle for (a) the pre-Gabrielle (2013) disturbance and (b) the nondeveloping P27L disturbance. Note, the data has been smoothed by using the 6-hour median coverage centered on each time.

4. Idealized Model Experiment Setup

- 6 hour simulations using CM1 model (Bryan and Fritsch 2002)
  - 100-km x 100-km x 25-km domain, open boundaries
  - 250-m horizontal grid spacing, 250-m average vertical grid spacing (stretched)
  - Morrison microphysics with graupel
  - No radiation, surface fluxes, or Coriolis force
- Sounding: 2nd Hurricane Nature Run (Nolan et al. 2013; Nolan and Mattocks 2014)
  - Idealized wind profile
  - Dry air removed by moistening layer under constant virtual temperature
  - DAIP altitude changed by removing DAIP and pasting DAIP relative humidity profile
- Convection forced with persistent convergence in lowest 1 km

5. Simulated 2–6-h Mean Cross Sections

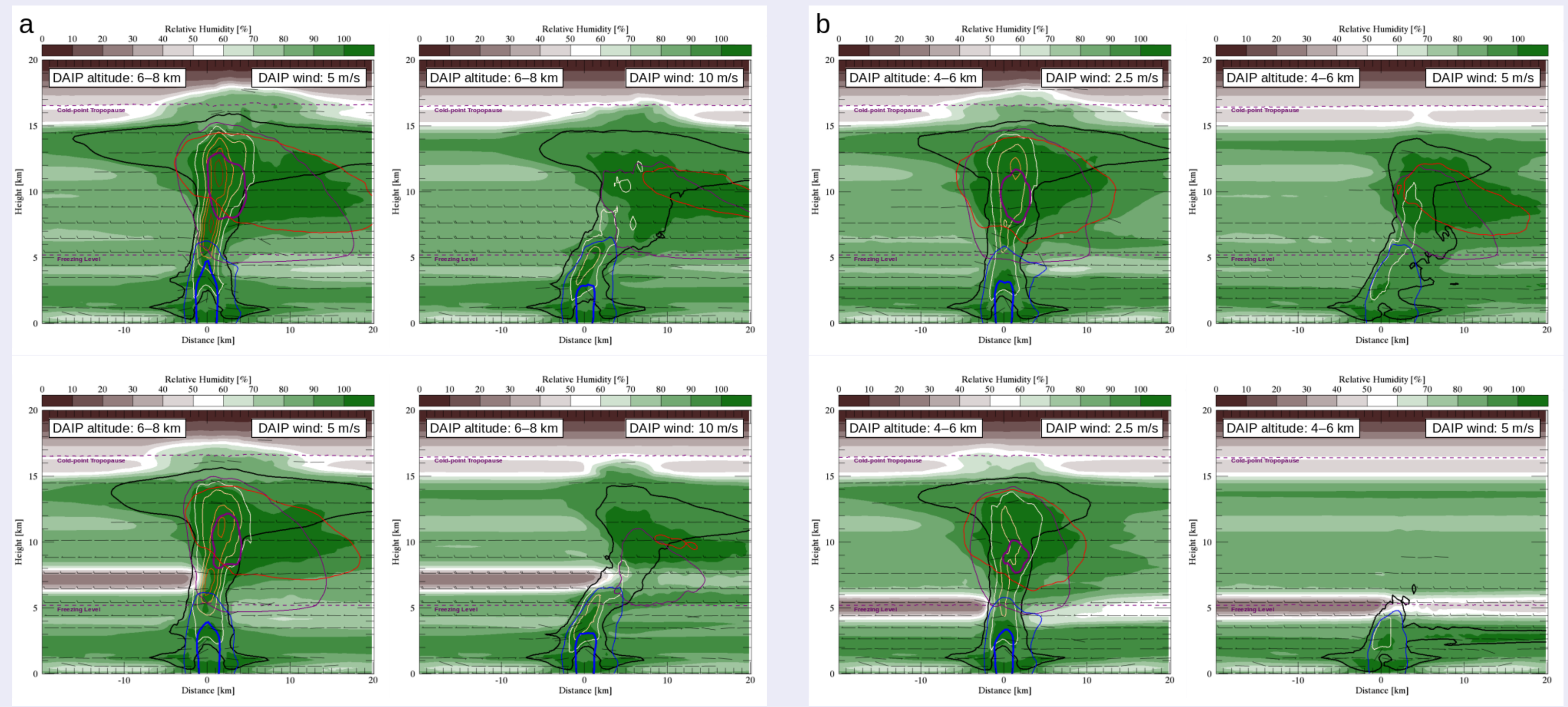

Fig. 5. Mean cross sections of relative humidity (shading), winds, and condensate for simulations with the DAIP between (a) 6 and 8 km and (b) 4 and 6 km. The top row depicts the simulations without a dry-air layer, while the bottom row depicts the simulations with a dry-air layer. The black line indicates the 1 g kg^{-1} cloud liquid mixing ratio and the orange-shaded contours indicate the updraft speed (contoured in 2 m s^{-1} intervals beginning with 2 m s^{-1}). The solid thin (thick) blue, red, and purple contours indicate the 1 g kg^{-1} (3 g kg^{-1}) rain water, snow, and graupel mixing ratios.

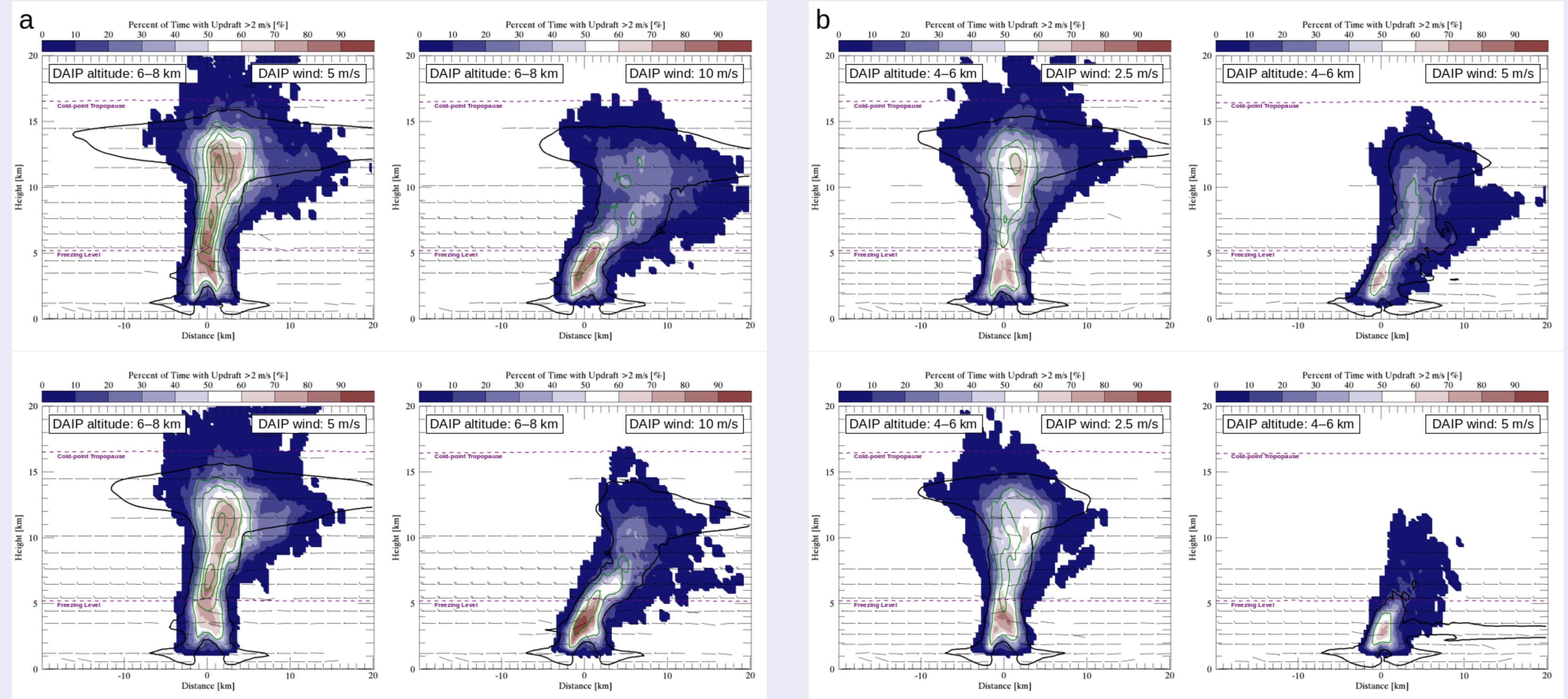

Fig. 6. As in Fig. 5, except shading indicates the percentage of time when the upward vertical motion exceeds 2 m s^{-1} between 2 and 6 h into the simulation and the mean updraft speed is indicated by the green contours (contoured in 2 m s^{-1} intervals beginning with 2 m s^{-1}).

6. Simulation Results

- DAIPs tend to have the following impacts:
  - weaker updrafts (Fig. 5)
  - reduce condensate (Fig. 5)
  - reduce updraft persistence (Fig. 6)
- DAIPs at a lower altitude have a stronger detrimental impact on deep convection (Figs. 5, 6) likely resulting from two key factors:
  - Specific humidity deficit is greater at a lower altitude for a given relative humidity
  - Updrafts are weaker at lower altitudes so the horizontal wind has a greater impact
- Stronger DAIP winds result in less condensate (Fig. 5), which impacts the disturbance by the following process:
  - Less condensate leads to less stratiform cooling
  - Less stratiform cooling produces less midlevel vorticity generation
  - Reduced midlevel vorticity generation inhibits midlevel vortex formation
  - Without a strong midlevel vortex to protect the convection, the DAIP continues to interfere with deep convection

7. Summary

- Examined Dry Air Inflow Pathways (DAIPs) using both observations and idealized modeling
- Key findings:
  - DAIPs appear to inhibit the establishment of persistent deep convection
  - DAIPs at a lower altitude or with stronger winds have a stronger detrimental impact on deep convection
  - DAIP inflow and dry air components appear to be of similar importance

8. References

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