32ND CONFERENCE ON HURRICANES AND TROPICAL METEOROLOGY

Dry Air, Midlevel Flow, and the Establishment of Persistent Deep Convection prior to Tropical Cyclogenesis

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1. Introduction

A number of recent studies (e.g., Davis and Ahijevych 2012; Smith and Montgomery 2012; Komaromi 2013; Zawislak and Zipser 2014; Helms and Hart 2015) have examined the structure and evolution of developing and nondeveloping tropical disturbances using observations. These studies consistently found that developing disturbances tend to have higher midlevel moisture in comparison to disturbances that fail to develop. Furthermore, Wang (2014) indicated midlevel moistening was important in maintaining sustained deep convection in a simulation of tropical storm Fay (2008). The study found that cumulus congestus acted as a net midlevel moisture source while deep convection was a midlevel moisture sink. For sustained deep convection to exist, the cumulus congestus must inject sufficient moisture at midlevels to offset the net moisture sink of the deep convection.

Dunkerton et al. (2009) proposed a theory describing the formation of a region of closed Lagrangian streamlines, or 'pouch', within an easterly wave that is protected from dry air intrusions. Although their analysis does not specifically mention features above 600 hPa, it is plausible that the appearance of closed Lagrangian streamlines at midlevels would produce a similar protected region. Such a region would enable convection to moisten the middle troposphere uninhibited by dry air intrusions, thus aiding the establishment of sustained deep convection as discussed by Wang (2014).

The present study aims to examine the combined role of midlevel flow patterns and dry air in modulating the time-dependent three-dimensional structure and evolution of convection in a tropical disturbance. We hypothesize that midlevel dry air inflow patterns (DAIPs) act to prevent the establishment of persistent deep convection, a key requirement of tropical cyclogenesis (TCG), by importing midlevel environmental dry air into the core convective region of a tropical disturbance and only once the DAIP is separated from the core convection can persistent deep convection become established. An example of a DAIP is given in Fig. 1. The next section briefly outlines the data and methodology and section 3 provides some preliminary results and conclusions.

2. Data and Methodology

To test our hypothesis, deep convective periods are classified as either persistent or nonpersistent. A deep convective period is considered to have initiated when the 6-hour median areal coverage of infrared brightness temperatures colder than 215 K exceeds 10% of a 100-km radius circle centered on a tropical disturbance. A deep convective period is classified as persistent if it lasts for at least 24 hours and is otherwise classified as nonpersistent. Additionally, the disturbance must be located over water for the first 24 hours after the start of the deep convective period. Finally, only cases where the deep convective period begins prior to the disturbance reaching tropical storm intensity are considered. An example of these criteria being applied is shown in Fig. 2.

Observations collected during the HS3 (Braun et al. 2015), GRIP (Braun et al. 2013), and PREDICT (Montgomery et al. 2011) field programs are examined to identify DAIPs. At present, DAIPs are subjectively identified by locating layers where observations suggest the existence of a continuous flow channel bringing dry air into a convective region. It is expected that, as work progresses, a more objective definition will be applied in identifying DAIPs. Additionally, tropical overshooting tops (TOTs; Monette et al. 2012) are used to determine the spatial relationship between the DAIPs and deep convection. Finally, environmental moisture profiles, obtained from the Atmospheric Infrared Sounder instrument (AIRS; Susskind et al. 2006) provide information on environmental moisture.

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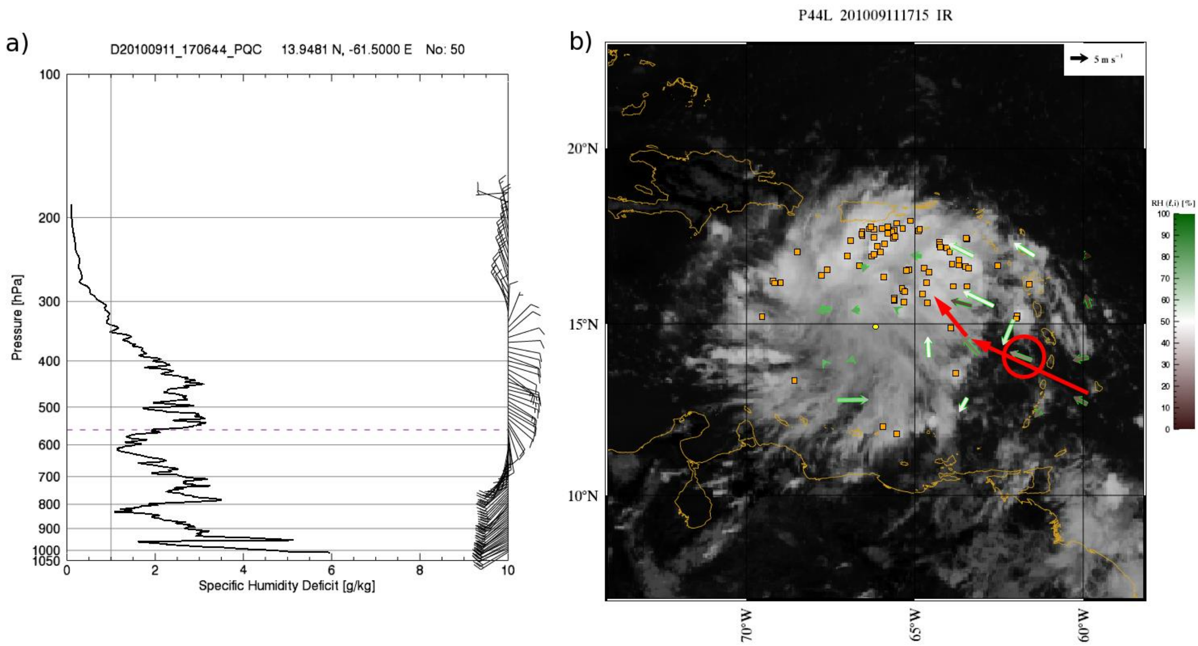

FIG. 1. Observations of a DAIP in the pre-Karl (2010) disturbance on 11 September 2010. Plotted are (a) specific humidity deficit and wind profiles, valid at 1706 UTC with the freezing level indicated by the dashed purple line, and (b) infrared satellite presentation, valid at 1715 UTC, overlaid with the wind vectors and relative humidity (vector shading) at the driest level between the freezing level and 300 hPa. Note, all winds are disturbance relative. Tropical overshooting tops occurring within the past 3 h are indicated by orange squares and the 700-hPa disturbance center is indicated by the yellow dot. The red arrows indicate the approximate extend of the DAIP and the red circle indicates the observation corresponding to the profile in panel (a).

3. Preliminary Results and Conclusions

The pre-Karl (2010) and pre-Gabrielle (2013) disturbances provide demonstrative examples of the potential importance of DAIPs in the evolution of a tropical disturbance. Fig. 1a depicts a DAIP observed in the pre-Karl disturbance that is located between the freezing level and 400 hPa. Within this DAIP, whose flow pattern is indicated in Fig. 1b, the disturbance-relative winds are bringing dry air into the active deep convection northeast of the disturbance center. By 2000 UTC ($\sim$ 3 h later), this deep convective region has completely collapsed.

In contrast, the active deep convection near the center of the pre-Gabrielle disturbance appears to be encased in a moist pouch-like region of midlevel flow (green circle, Fig. 3b). A DAIP (see sounding, Fig. 3a) is drawing dry air from an extensive region of dry midlevel air located over the western Atlantic and does not appear to penetrate the pouch-like feature. Furthermore, the active deep convection within this pouch-like feature persists through the diurnal convective minimum and it is during this deep convective period that the disturbance is designated a tropical depression. It is worth mentioning that a similar midlevel pouch-like feature appears to be separating the deep convection from a DAIP during the genesis of Karl (not shown).

Preliminary analyses suggest that DAIPs may be present during every convective episode and could play an important part in preventing the establishment of persistent deep convection. In both the pre-Karl and pre-Gabrielle disturbances, persistent deep convection appears to become established when the DAIP is prevented from reaching the core convection by a midlevel pouch-like feature. This interpretation is consistent with the findings of both Dunkerton et al. (2009), that the pouch is a favorable location for deep convection, and of Wang (2014), that deep convection is sensitive to environmental moisture content.

The present study aims to test the hypothesis that DAIPs prevent the establishment of persistent deep convection and that persistent deep convection cannot be established until the DAIP is separated from the core convection. A variety of observations are used to identify DAIPs and persistent and nonpersistent deep convective periods. Preliminary findings suggest that the presence of a DAIP bringing dry midlevel air into a deep convective region is associated with nonpersistent deep convection. In contrast, DAIPs that are separated from the deep convection are associated with the establishment of persistent deep convection. Future work will aim to extend the observational analysis to additional cases.

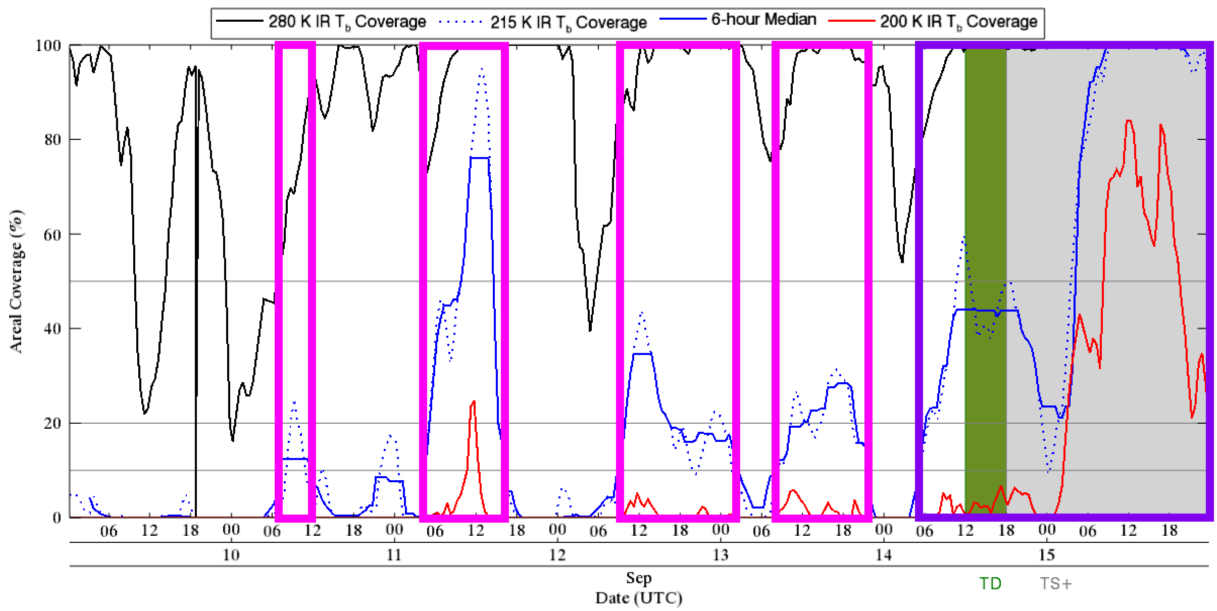

FIG. 2. Time series of percent areal coverage of brightness temperatures over a 100-km radius circular area for the pre-Karl (2010) disturbance. The solid black, dotted blue, and solid red lines indicate the coverage of brightness temperatures below 280 K, 215 K, and 200 K, respectively. The solid blue line indicates the 6-hour median of the 215 K coverage. The purple and magenta boxes denote periods of persistent and nonpersistent deep convection, respectively.

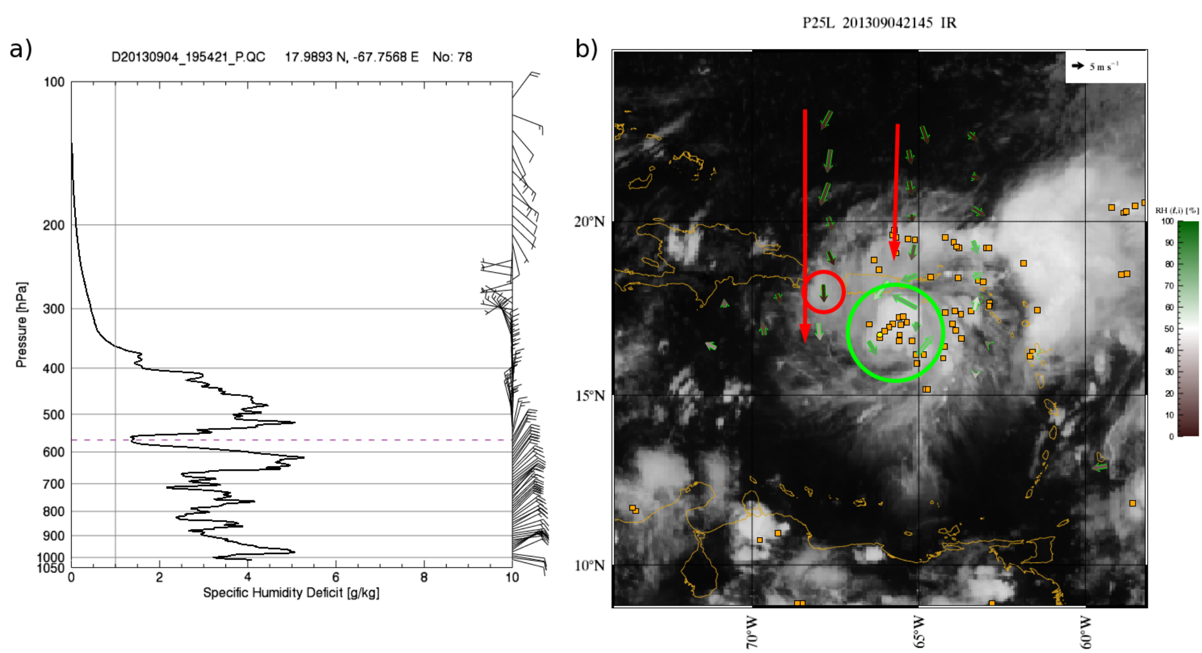

FIG. 3. As in Fig. 1, except for a DAIP observed in the pre-Gabrielle disturbance. The sounding and satellite image are valid at 1954 UTC and 2145 UTC 4 September 2013, respectively. The green circle denotes the approximate location of a midlevel pouch-like region separating the DAIP from the core convection.

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