Tropical Deep Convection, Downdrafts, and Stable Layers: Implications for Tropical Cyclone Formation and Intensification

Charles N. Helms (charles.n.helms@nasa.gov)

NASA Goddard Space Flight Center and Universities Space Research Association

1. Motivation, Background, and Hypothesis

Helms (2018) Simulations

- Simulations of tropical deep convection exposed to midlevel dry air flow layers (Fig. 1a)
- Initial sounding taken from the Second Hurricane Nature Run (HNR2; Nolan et al. 2013, Nolan and Mattocks 2014)
  - Included stable layer at ∼3 km (Fig. 1b)
- Simulated downdrafts appeared to stop at stable layer (Fig. 2a–c)

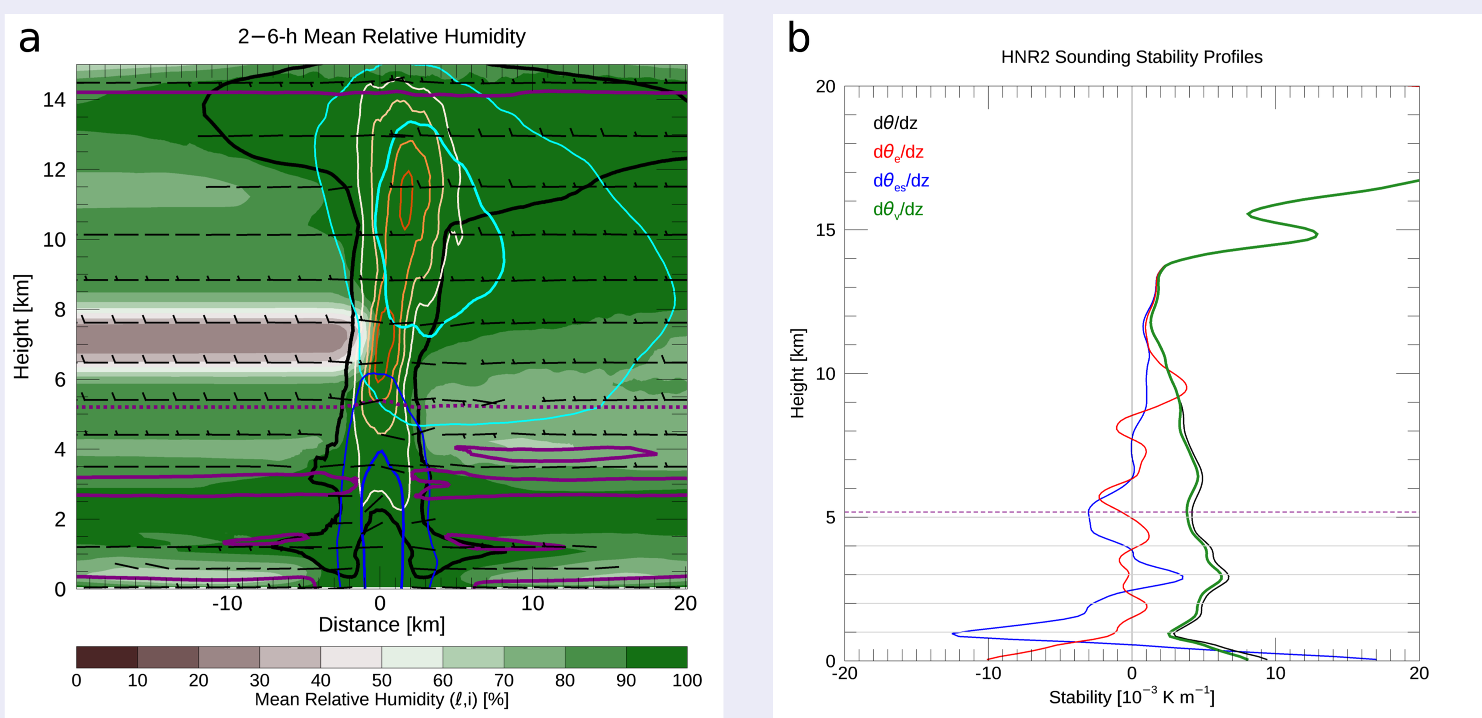

Fig. 1. **(a)** Cross section of 2–6-h mean relative humidity (shading) through center of the Helms (2018) simulation. Overlaid are averages of the horizontal winds (barbs in knots), cloud extent (black contour), updraft speed contoured at 2 m s^{-1} intervals between 2 m s^{-1} and 10 m s^{-1} (white-to-orange contours), freezing level (dashed purple line), 1 g kg^{-1} and 3 g kg^{-1} frozen pricipitation mixing ratio (thin and thick cyan contours, respectively), and 1 g kg^{-1} and 3 g kg^{-1} liquid precipitation mixing ratio (thin and thick blue contours, respectively). The thick purple contour indicates the extent of the stable layers (6 K km^{-1} $d\theta_v/dz$). **(b)** Initial stability profile as represented by the vertical gradients of potential temperature (black), equivalent potential temperature (red), saturation equivalent potential temperature (blue), and virtual potential temperature (green).

Tropical Cyclone (TC) Ventilation

- Tang and Emanuel (2010, 2012)
- Ventilation of TC by midlevel dry air negatively impacts intensity
- Two pathways for midlevel dry air to impact TC intensity:
  - Dry air directly entrained into TC eyewall, reducing thermal efficiency of TC heat engine
  - Dry air encourages low-entropy downdrafts that flood TC inflow layer with low equivalent potential temperature (θ_e) air that inhibits deep convection

Hypothesis: Stable layers can prevent downdrafts from flooding the TC inflow layer with low θ_e air

2. Model Description

Cloud Model 1 (CM1)

- Bryan and Fritsch (2002)
- 100-km x 100-km x 25-km domain, 250-m grid spacing
- Initial sounding taken from HNR2
- Surface convergence imposed for duration of 6-h simulations
- Deep convection continuously exposed to midlevel dry air flow layer with 5 m s^{-1} zonal winds
- Morrison microphysics; no radiation, surface fluxes, or Coriolis

3. Analysis of Simulations

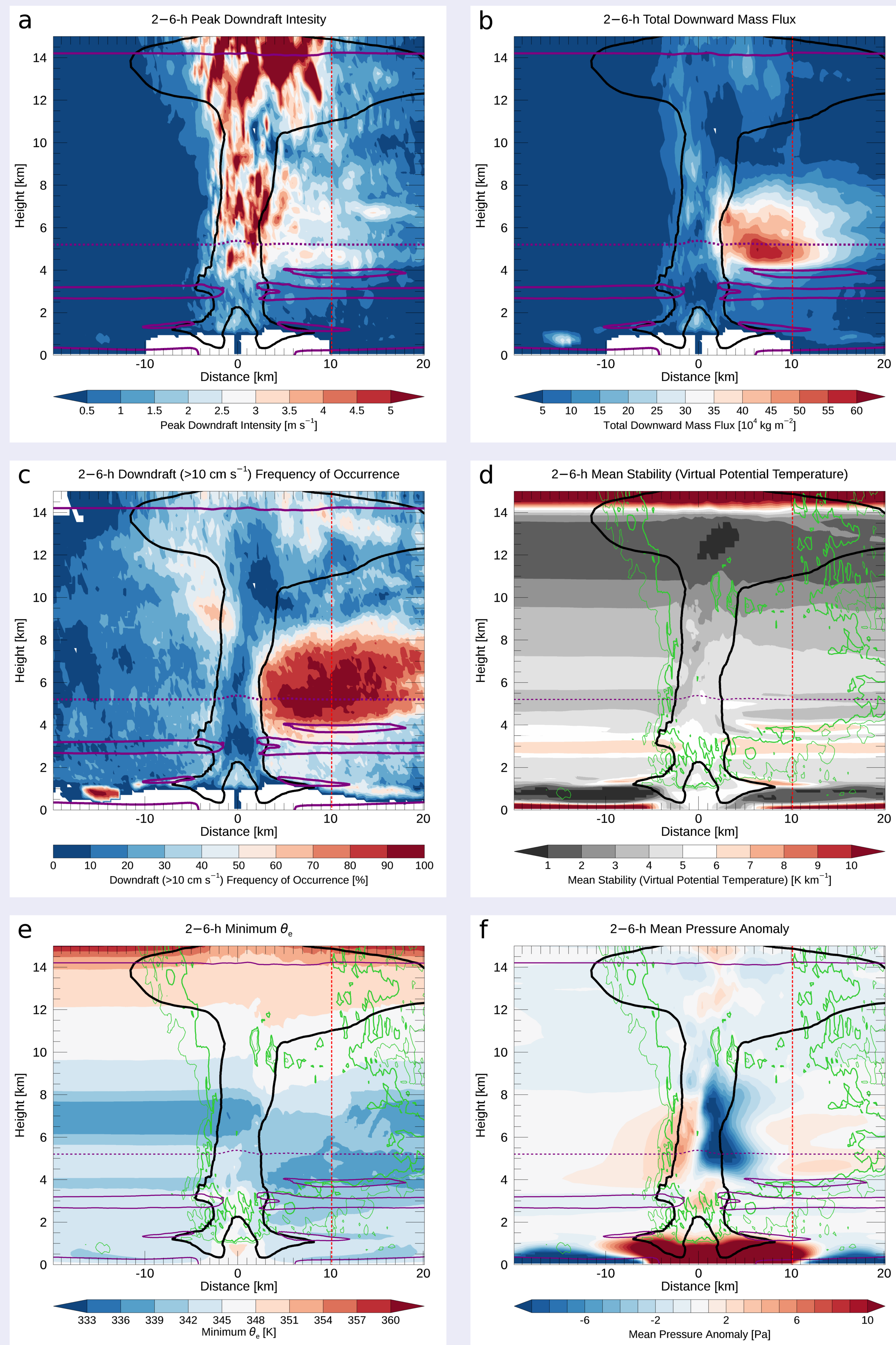

Fig. 2. As in Fig. 1a, except cross sections are of **(a)** 2–6-h peak downdraft intensity, **(b)** 2–6-h total downward mass flux, **(c)** 2–6-h frequency of occurrence for downdrafts exceeding 10 cm s^{-1}, **(d)** 2–6-h mean stability computed using virtual potential temperature, **(e)** 2–6-h minimum θ_e, and **(f)** 2–6-h mean pressure anomaly. The thin and thick green contours indicate the extent of 50 cm s^{-1} and 100 cm s^{-1} 2–6-h peak downdraft intensity. The vertical red dashed line indicates the position of the cross sections in Fig. 3. Otherwise, overlays are as in Fig. 1a.

4. Results

Preliminary Analysis

- Majority of downdrafts unable to penetrate stable layer (Fig. 2a–d)
- Weak downdrafts below stable layer may have formed in situ
- Lowest θ_e air remains contained above stable layer (Fig. 2e)
- Downdraft weakening is not due to excessive mass detrainment below stable layers, which would produce a high pressure anomaly beneath the stable layer (Fig. 2f)
- Downdrafts and low-θ_e air inhibited over wide area (Fig. 3)

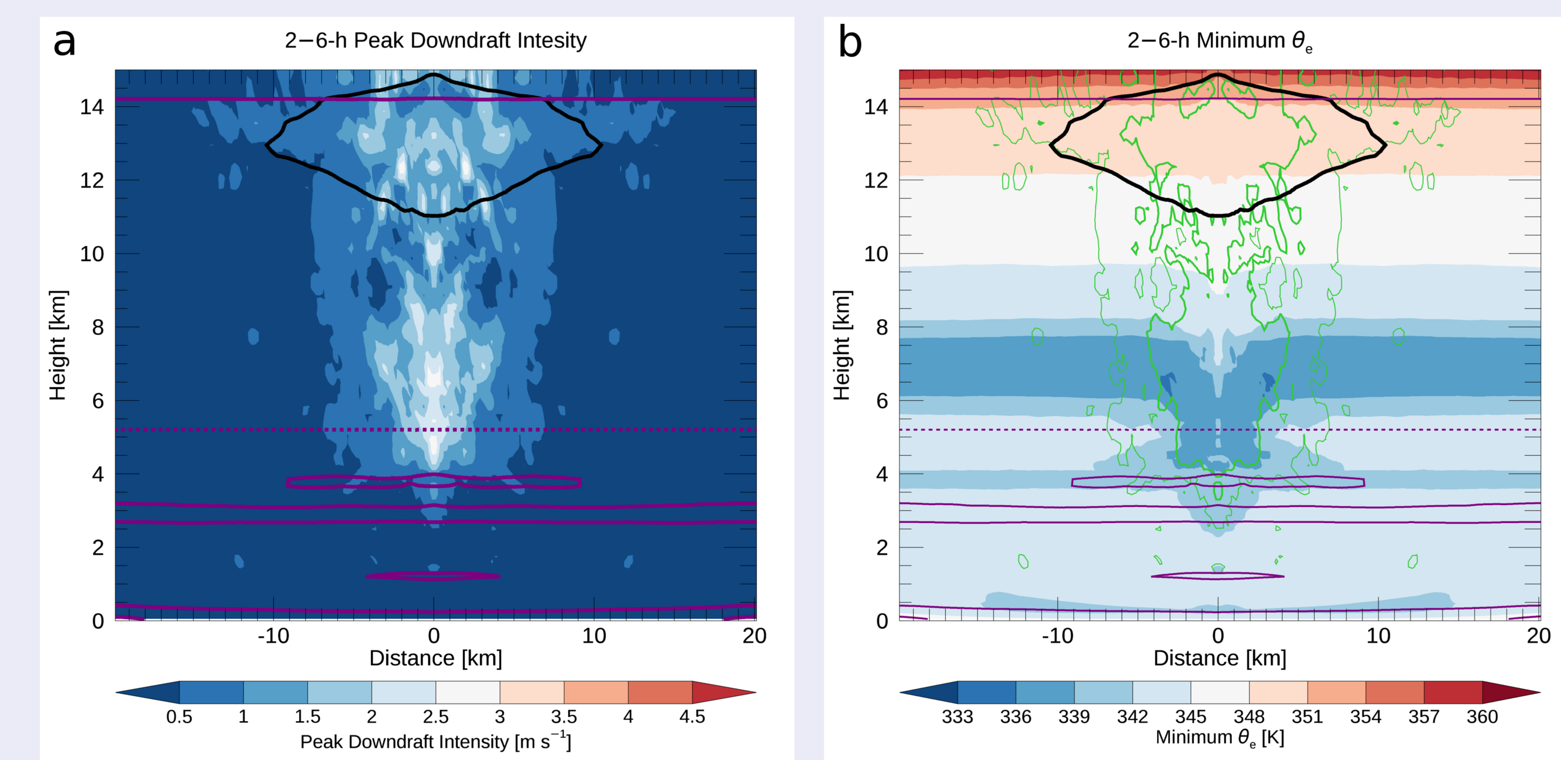

Fig. 3. **(a)** 2–6-h peak downdraft intensity, as in Fig. 2a, and **(b)** 2–6-h minimum θ_e, as in Fig. 2e, except the cross sections are oriented meridionally at the position indicated by the vertical red dashed line in Fig. 2.

5. Summary

- **Goal**: Examine the potential for stable layers to prevent downdrafts from flooding the TC inflow layer with low θ_e air that would inhibit TC formation and intensification
- **Method**: High-resolution idealized simulations of deep convection with plans to analyze airborne radar and dropsonde observations
- **Results**: Preliminary analysis indicates the potential for stable layers to inhibit downdrafts and prevent the lower troposphere from being flooded by low θ_e air that could inhibit TC intensification. Additional work is required to fully test the hypothesis and eliminate other possible explanations.

6. References

- Bryan, G. H., and J. M. Fritsch, 2002: A benchmark simulation for moist nonhydrostatic numerical models. *Mon. Wea. Rev.*, **130**, 2917–2928.
- Helms, C. N., 2018: Dry air, midlevel flow, and the persistence of deep convection in Atlantic tropical disturbances. *Doctoral Dissertation*, University at Albany, 148p.
- Nolan, D. S., R. Atlas, K. T. Bhatia, and L. R. Bucci, 2013: Development and validation of a hurricane nature run using the Joint OSSE Nature Run and the WRF model. *J. Adv. Model. Earth Syst.*, **5**, 1–24.
- Nolan, D. S., and C. A. Mattocks, 2014: Development and evaluation of the second hurricane nature run using the Joint OSSE Nature Run and WRF model. *Extended Abstracts, 31st Conf. on Hurricanes and Tropical Meteorology*, San Diego, CA, Amer. Meteor. Soc., P91.
- Tang, B. and K. Emanuel, 2010: Midlevel ventilation's constraint of tropical cyclone intensity. *J. Atmos. Sci.*, **67**, 1817–1830.
- Tang, B. and K. Emanuel, 2012: A ventilation index for tropical cyclones. *Bull. Amer. Meteor. Soc.*, **93**, 1901–1912.

Acknowledgments

This work was supported by an appointment to the NASA Postdoctoral Program (NPP) at the NASA Goddard Space Flight Center, administered by Universities Space Research Association under contract with NASA. The author would also like to acknowledge high-performance computing support for the Helms (2018) simulations from Yellowstone (ark:/85065/d7wd3xhc) provided by NCAR's Computational and Information Systems Laboratory, sponsored by NSF.