Changes in the Precipitation Structure of Tropical Cyclones After Landfall

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1. Introduction

Background

- Understanding how tropical cyclones (TCs) decay upon landfall will improve predictions of inland flooding and damaging winds;
- Prior work has largely focused on post-landfall decay of TC intensity, which decreases exponentially following landfall (DeMaria and Kaplan 1995);
- Limited prior modeling studies have shown post-landfall weakening of TC is stronger with greater surface roughness and less soil moisture (Hlywiak and Nolan 2021);
- However, there have been no prior large-sample studies focused on landfall impacts on TC precipitation structure.

Research Question and Hypothesis

- **Research Question: How does landfall impact the precipitation structure of TCs?**
- **Hypothesis: Precipitation will weaken and broaden as the TC moves inland, decaying most quickly near the eyewall.**

2. Data and Methods

Datasets

- **TC track data:** used 6-hour track data to collect all hurricane-strength North Atlantic TCs at landfall from 1995–2017 that remained over land for >=12 consecutive hours (N=28 TCs; Landsea and Franklin 2013);
- **Vertical wind shear data:** Computed environmental 850–200-hPa vertical wind shear impacting the TC for each 6-hour track point computed from ERA-5 reanalysis data for use as azimuthal reference frame (Davis et al. 2008);
- **Defining landfall time:** Used 1 km x 1 km USGS Global Self-consistent, Hierarchical, High-resolution Geography Database to calculate landfall time;
- **Precipitation structure data:** Extracted 0.2° x 0.2° 1-h gridded WSR-88D radar reflectivity data from within 500 km of landfalling TCs (Homeyer and Bowman 2017).

Methods

- Separated radar data into quartiles based on time since landfall: 0–6 h, 6–12 h, 12–18 h, and 18–24 h;
- Analysis focuses on examining post-landfall evolution of the horizontal and vertical structure of TC precipitation.

3. Results: How Does the Horizontal Structure of TC Precipitation Change After Landfall?

Overview

Analyzing the changes in the horizontal structure of TC precipitation following landfall.

Synopsis

1. Strength and vertical extent of precipitation decay over land, which is especially present in the left-of-shear quadrants of the eyewall (Figs. 1 and 2).
2. Intense convection shifts from the eyewall to outer radii of the downshear left quadrant (Figs. 1 and 2).
3. As TCs remain over land, the structure becomes broader and more asymmetric (Figs. 1 and 2).

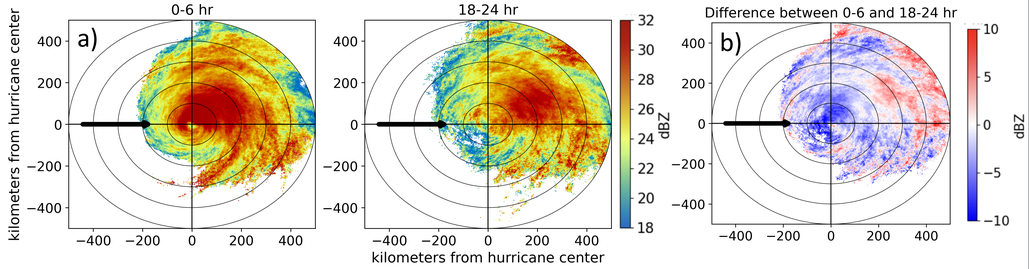


Fig. 1: TC-relative plan-view plots showing the heights less than 4 km for (a) median reflectivity (dBZ) for 0–6 and 18–24 h after landfall, and (b) the difference between these periods. Radar data and vertical wind shear are rotated eastward for consistency, with black arrows indicating shear direction, and rings indicting each 100km distance from 0-500km.

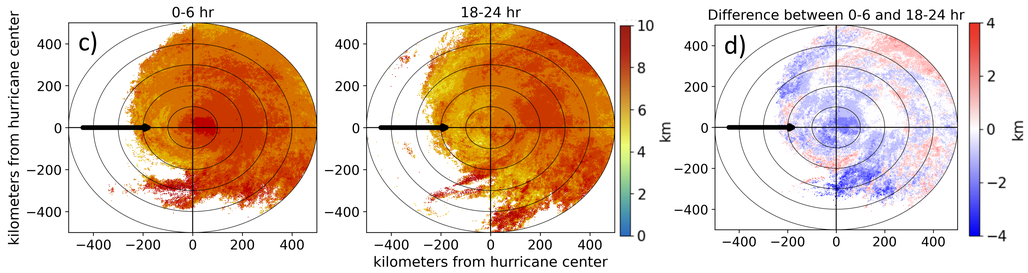


Fig. 2: As in Fig. 1, but panels (c) and (d) show 10-dBZ echo top heights (km) and their differences.

4. Results: How Does the Precipitation Structure Change with Distance from TC After Landfall?

Overview

Focus on investigating how TC precipitation structure changes with distance from the TC over land.

Synopsis

1. Precipitation intensity and height decays most quickly near the eye of the TC in 6 h after landfall (Figs. 3 and 4).

2. Outer rainbands show marginal changes and appear to propagate outward with increasing time (Figs. 3 and 4).

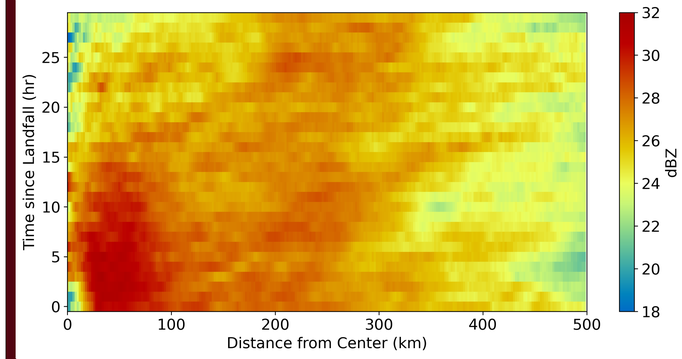


Fig. 3: Joint histogram of median reflectivity (dBZ) for heights < 4 km as function of distance from the TC versus time since landfall (h).

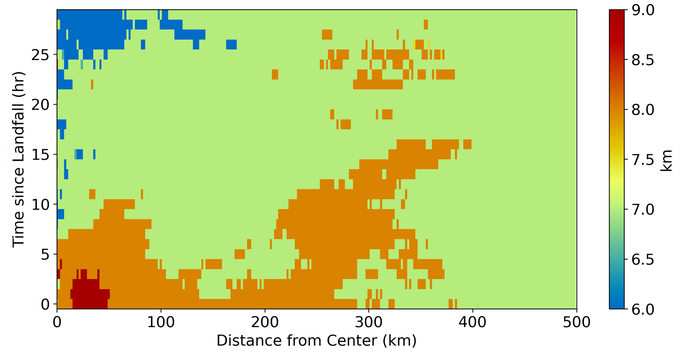


Fig. 4: As in Fig. 3, but for median 10-dBZ echo top (km).

5. Results: How Does the Vertical Structure of Precipitation Change After Landfall?

Overview

Comparing the post-landfall changes in the intensity of precipitation structure with height following landfall.

Synopsis

1. Convection weakens and becomes shallower after landfall (Fig. 5 bottom).
2. Distribution of reflectivity narrows suggesting predominance of stratiform precipitation (Fig. 5 bottom).

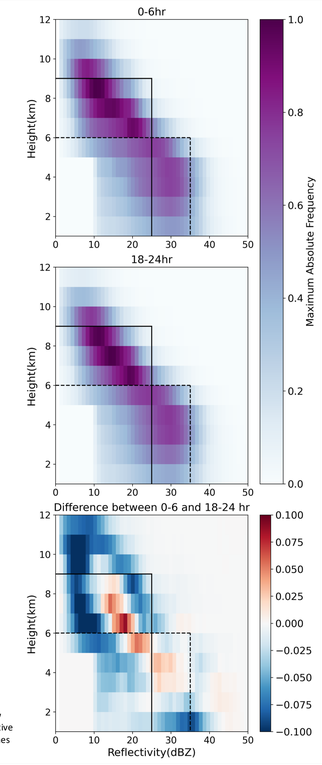


Fig. 5: Contoured frequency by altitude diagrams of reflectivity (dBZ) for 0–6 hr (top), 18–24 hr (middle), and their difference (bottom) since landfall. Colors show normalized frequency (top/middle) and differences (bottom), with positive/negative values indicating higher/lower frequencies at 18–24 hr. Solid and dashed black lines mark the 9-km/25-dBZ and 6-km/35-dBZ levels, respectively.

6. Summary and Discussion

We investigated the vertical and horizontal structure of precipitation for 28 landfalling hurricanes.

The key conclusions of this study were:

- Precipitation structure weakens in both strength and vertical extent as TCs move over land;
- As TCs remain over land, structure becomes broader and more asymmetric;
- Distribution of convection narrows with time indicating dominance of stratiform precipitation.

As seen from results, forecasters should be prepared that hazards may become concentrated downshear-left as TCs move inland.

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