Characterization of Vertical Thermodynamic Structures in Tropical Cyclones from GNSS Radio Occultation and Dropsondes

Kevin J. Nelson, Chi O. Ao, and Kuo-Nung Wang
Ionospheric and Atmospheric Remote Sensing
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

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Email:
kevin.j.nelson@jpl.nasa.gov

1. Introduction

- Biondi et al. (2011, 2013, 2015) and Vergados et al. (2013, 2014) are the first uses of GNSS RO retrievals in tropical cyclones (TCs)
  - Lasota et al. (2018, 2020) follow-on studies
- Rogers (2021) stresses the need for accurate temperature and humidity measurements in the tropical cyclone middle troposphere and boundary layer (TCBL) as well as TCBL height observations (see Zhang et al. 2011, 2013 and others)
  - Dropsonde observations of TCs limited to those that pass through the TCBL from above; launched around 10 km and 3 km
- Observations from passive microwave and infrared sounders in TCs limited due to substantial amounts of clouds and precipitation
  - MW low vertical resolution; significant signal attenuation in IR
- Global Navigation Satellite Systems (GNSS) radio occultation (RO) can provide early TC thermodynamic observations in all weather conditions that can complement dropsondes

2. Data and Methodology

- GNSS RO atmPrf and wetPf2 (1D-Var) retrievals from UCAR
  - COSMIC-1 (2006-2019) reprocessed in 2021
  - COSMIC-2 (2019-2023) NRT product

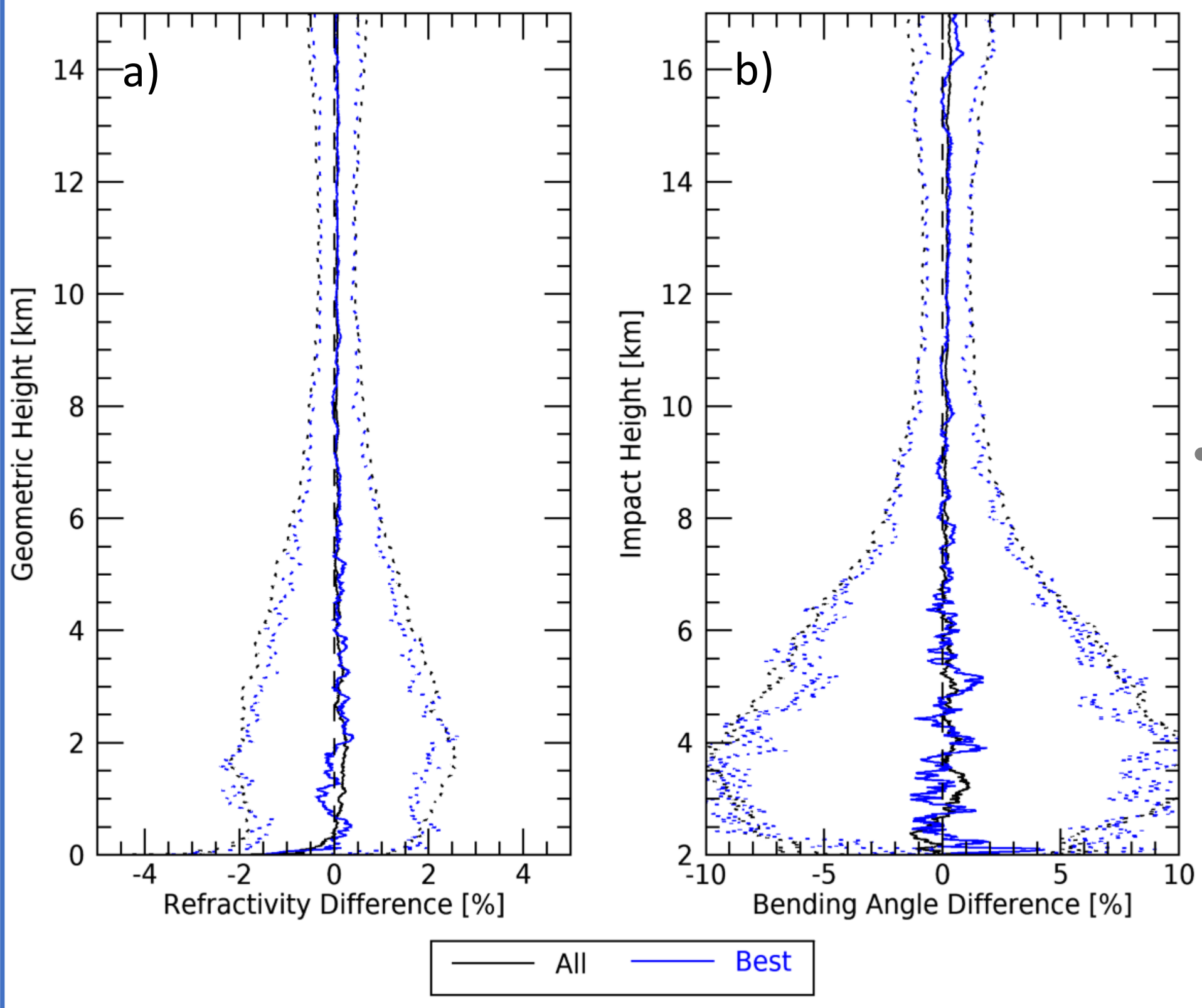


Figure 1: Median (solid) ± median absolute deviation (MAD, dotted) a) refractivity and b) bending angle differences between colocated COSMIC-1 and COSMIC-2 RO profiles

- Overall median N and α differences between COSMIC-1 and COSMIC-2 are 0.2% or less across all levels, datasets combined

- Tropical cyclone (TC) best-track information taken from International Best-Track Archive for Climate Stewardship (IBTrACS, Knapp et al. 2010)
- Tropical Cyclone Dropsonde Research and Operations Product Suite (Zawislak, 2022) used for validation and comparison
- Individual RO profiles colocated to TCs using IBTrACS
  - Best-track position interpolated to time of RO
  - Only colocations at 1 km height within 500 km are accepted

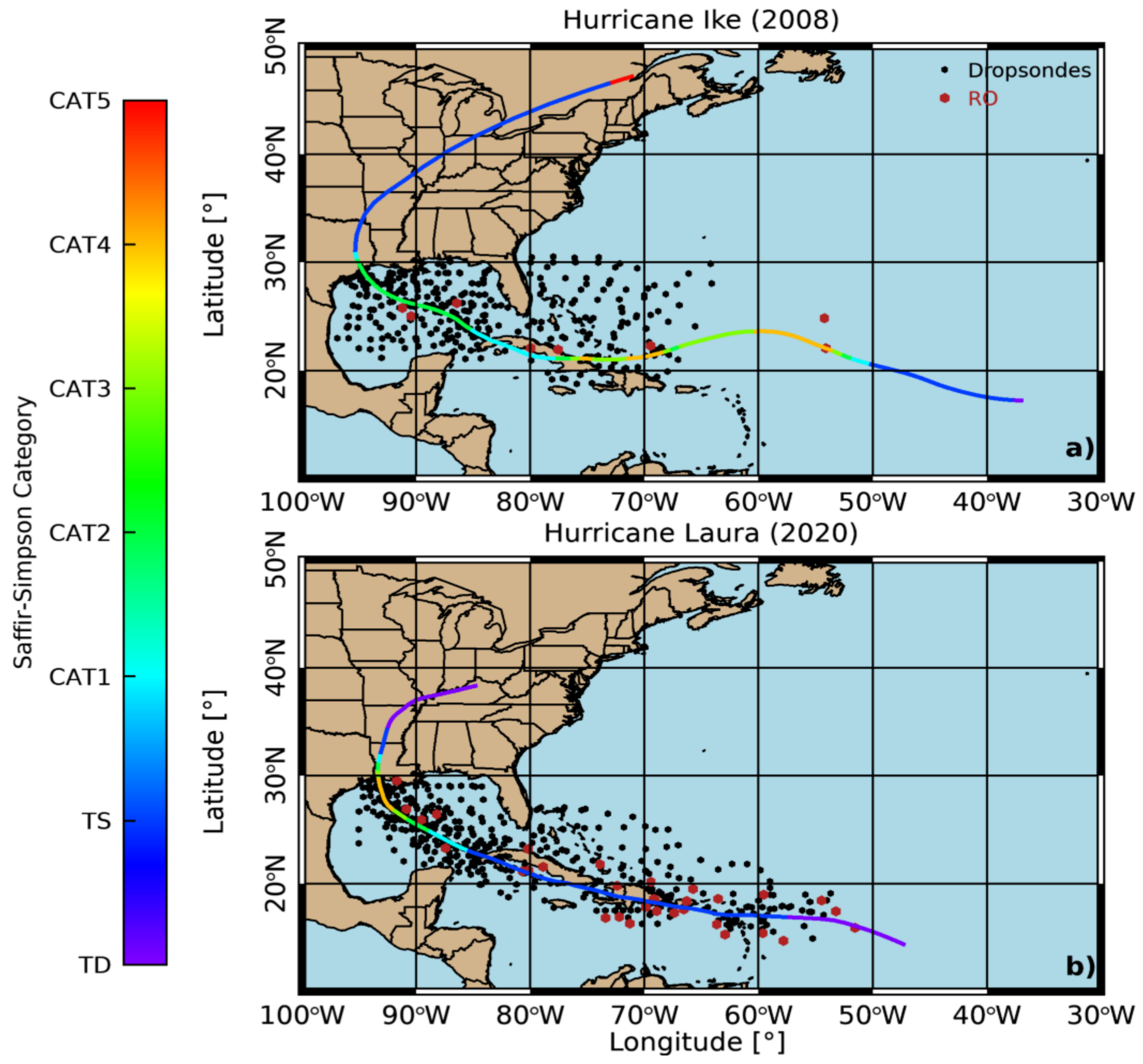


Figure 2: a) Map showing track of Hurricane Ike (2008) and b) Map showing track of Hurricane Laura (2020) with tracks colored by Saffir-Simpson intensity category. Dropsondes launches as part of reconnaissance flights and/or field campaigns indicated by black dots. RO profiles colocated with TC tracks at 1 km shown in red.

- Refractivity in dropsondes computed using forward model from Aparicio et al., (2009):

$$N = (n-1)\cdot 10^6 = a_1\frac{P}{T} + a_2\frac{e}{T} + a_3\frac{e}{T^2}$$

3. Profile Statistics

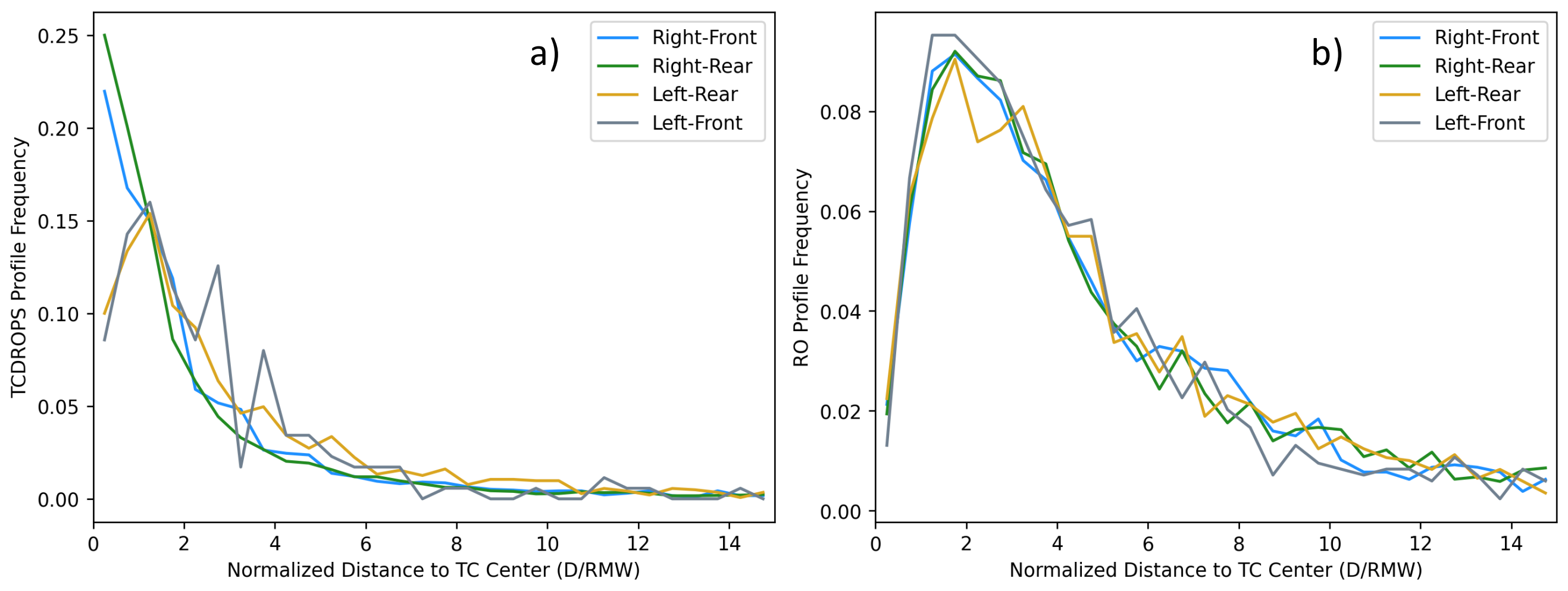


Figure 3: Azimuthal sampling PDFs binned by normalized distance from TC center for a) TCDROPS and b) RO profiles for each storm-relative quadrant.

- Sampling between RO and TCDROPS agrees for both datasets well except for left-front quadrant where dropsondes are launched much less frequently

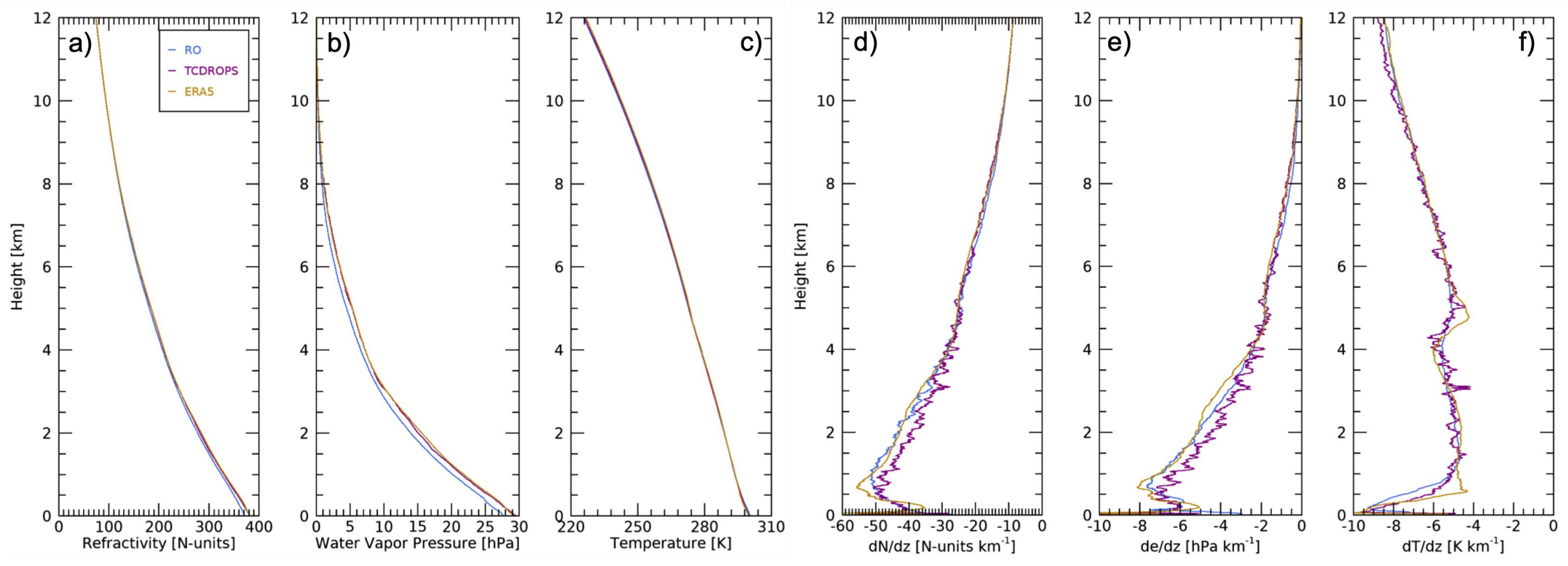


Figure 4: Median profiles of a) atmospheric refractivity [N-units], b) water vapor pressure [hPa], c) absolute air temperature [K], d) vertical refractivity gradient [N-units km^{-1}], e) vertical water vapor pressure gradient [hPa km^{-1}], and f) vertical temperature gradient [K km^{-1}] for all RO/TCDROPS colocated pairs.

- Distinct gradients in lowest reaches of median profiles indicate that GNSS RO can observe the TC boundary layer (TCBL)

4. Results from Middle Troposphere

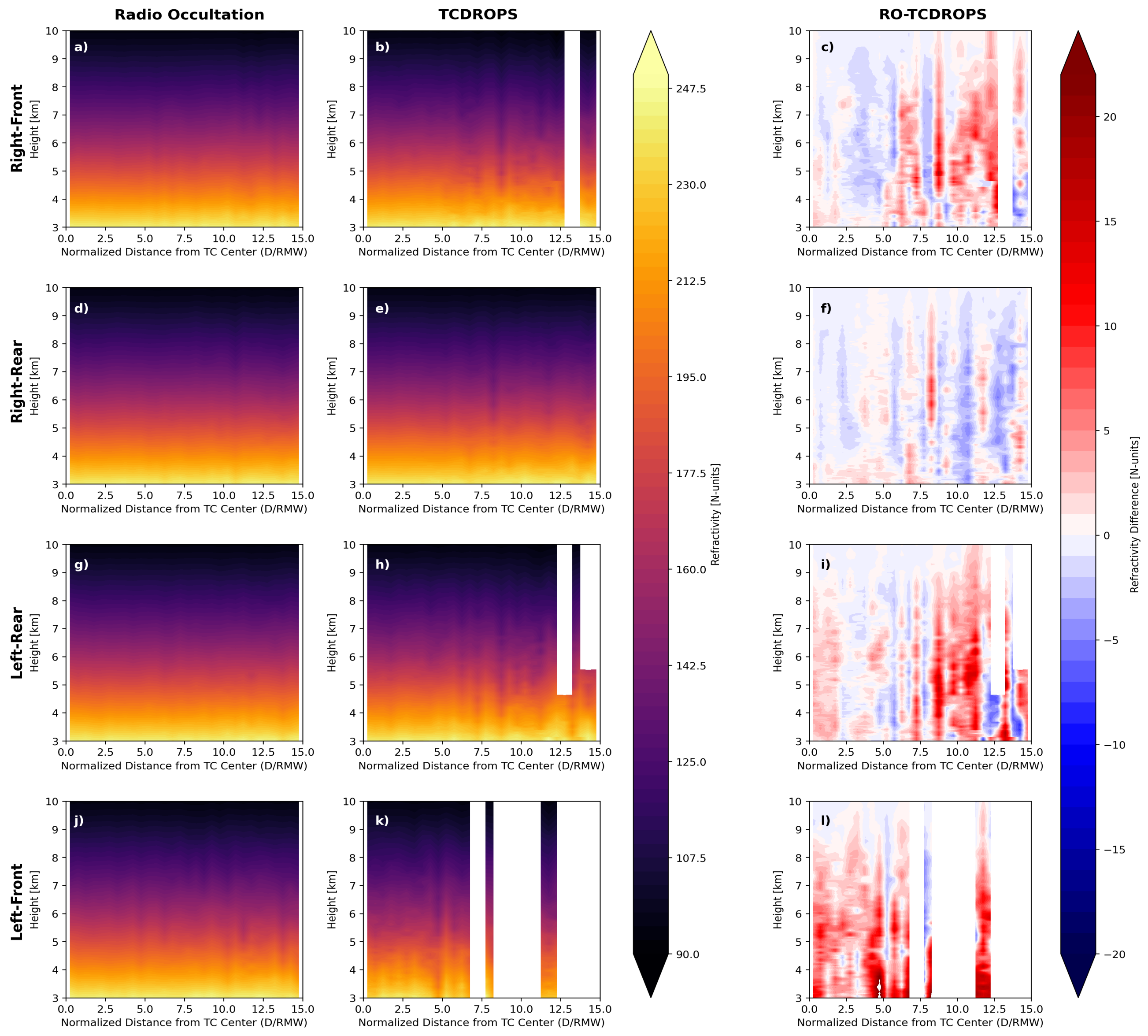
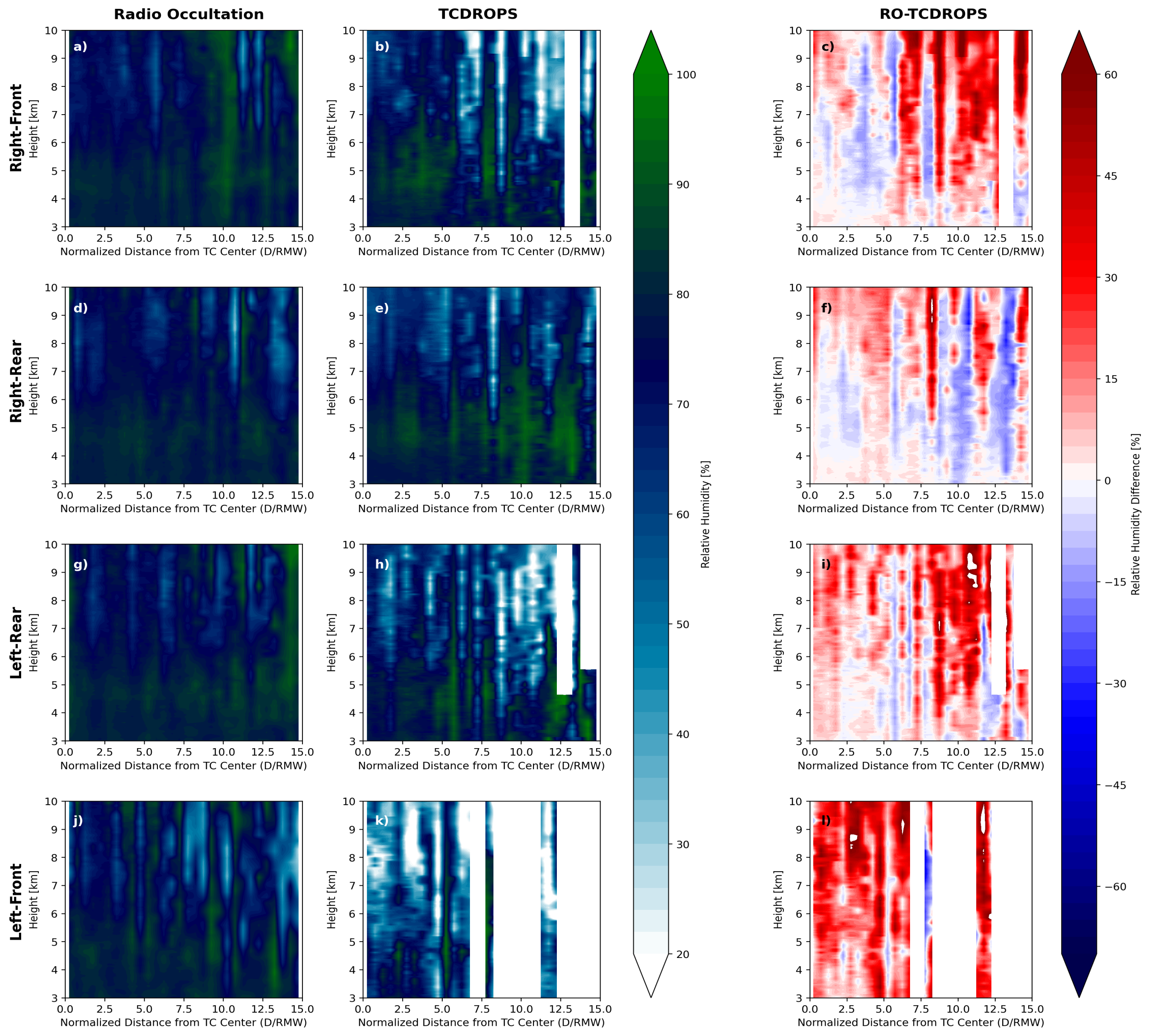


Figure 5/6: Azimuthal composites of refractivity (top) and relative humidity (bottom) for GNSS RO (L), TCDROPS (C), and (R) their differences for each storm-relative quadrant.



5. Results from TCBL

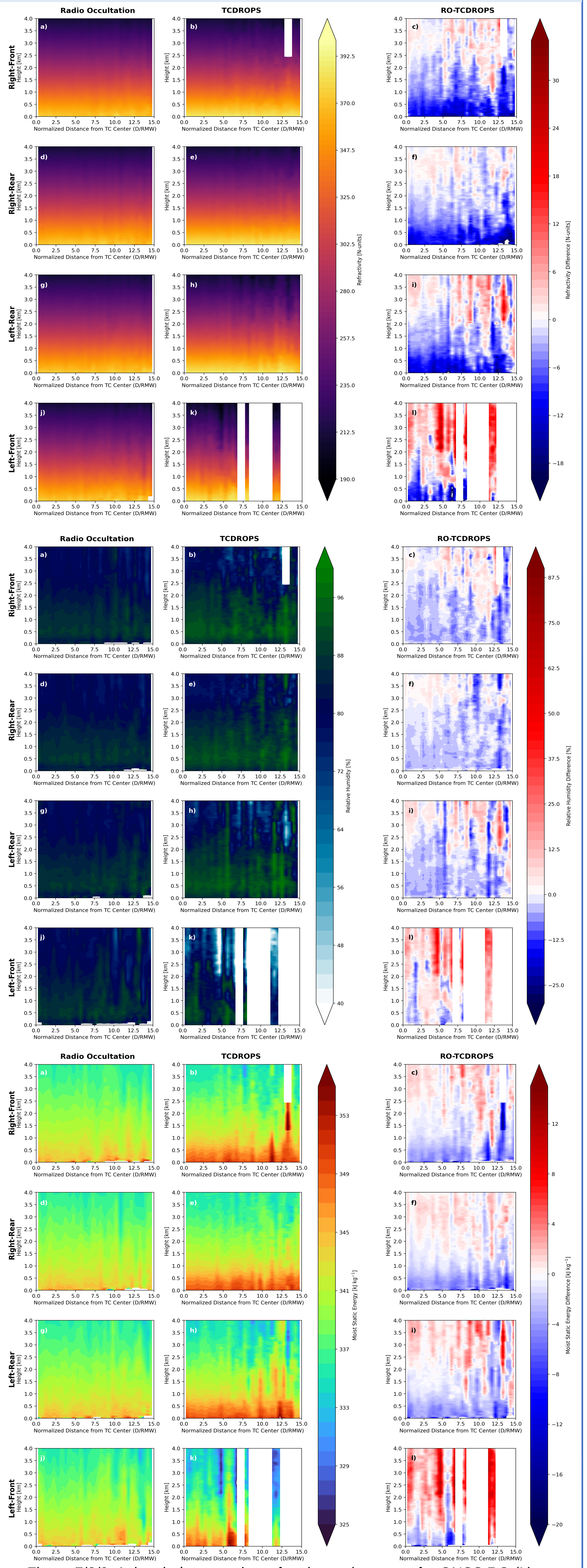


Figure 7/8/9: Azimuthal composites of moist static energy for GNSS RO (L), TCDROPS (C), and the difference (R) for each storm-relative quadrant.

6. Conclusions

- GNSS RO can provide thermodynamic profiles in all weather conditions due to its insensitivity to clouds and precipitation
- GNSS RO does currently have some deficiencies/biases, but results are promising overall, and corrections are being developed
- GNSS RO can augment current dropsonde capabilities between reconnaissance flights
- Differences between GNSS RO and TCDROPS thermodynamic composites reveal interesting structures potentially related to moisture/energy transport, TC ventilation, TC intensification