Airborne Radio Occultation Observations of Mid-Tropospheric Features in Tropical Cyclones

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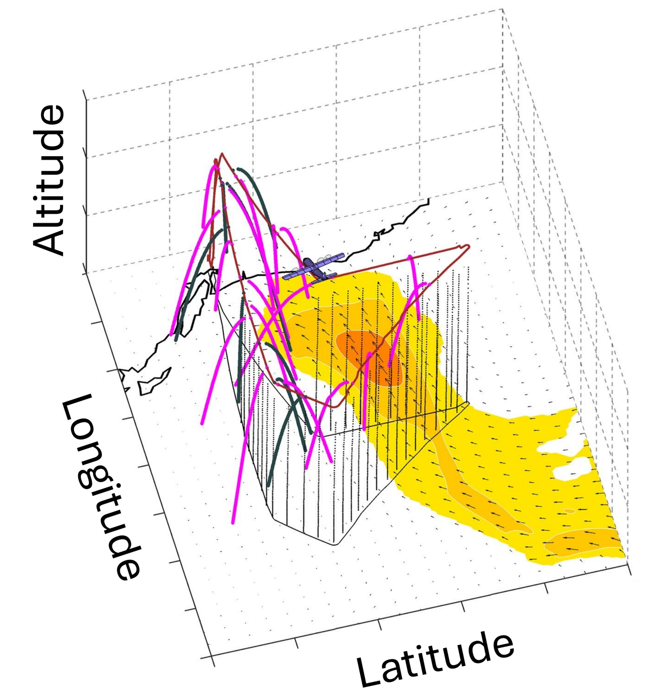
ARO collects thermodynamic profiles in the environment surrounding the flight path

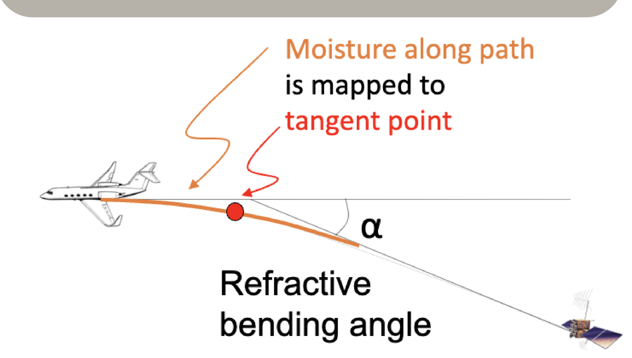
- ARO profiles are concentrated in an area of interest
- Current methods (closed loop, geometric optics) allow profiles to go from flight level (14km) to 6km

ARO samples away from the flightpath



Haase et. al. 2021

Tangent point drift allows ARO to collect data up to 400 km from the flightpath

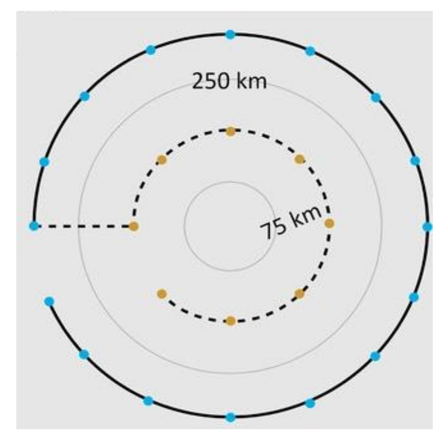


Courtesy B. Cao

ARO on NOAA G-IV flights circling the storm center samples across the TC core

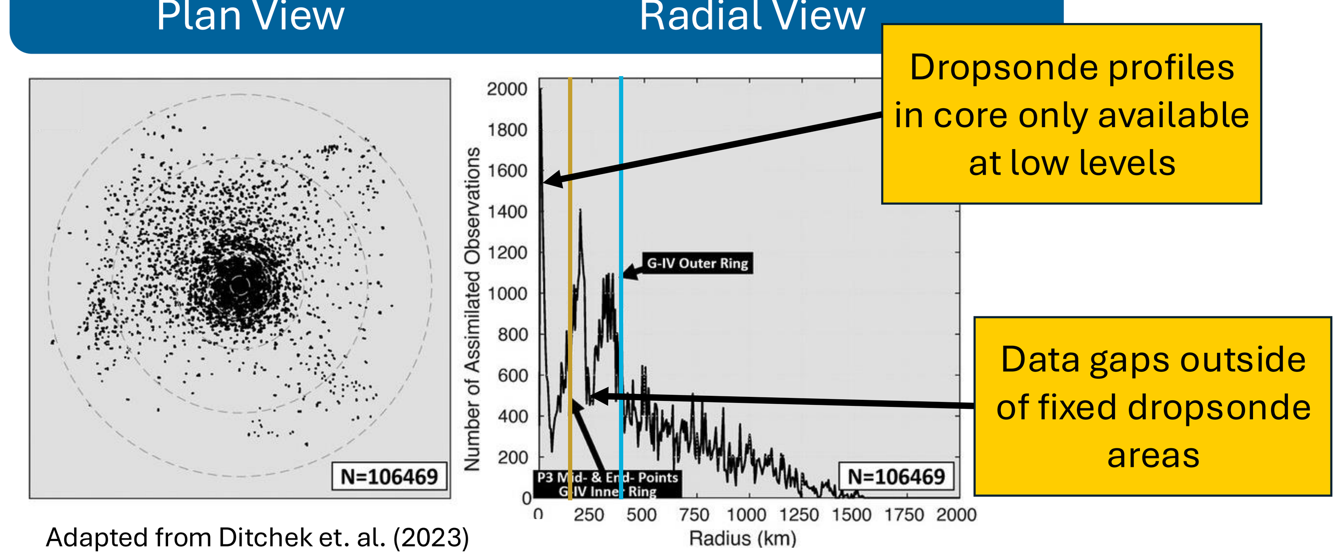
- Tangent point drift generates a near uniform distribution of ARO profiles, supplementing our observations beyond traditional dropsonde releases at fixed radii.
- In intense hurricanes, the G-IV high altitude dropsonde deployments do not sample the storm center so there are few observations of mid-level thermodynamics. ARO profiles supplement this missing data.
- It takes ~10min to collect an ARO profile, enabling sampling across the synoptic environment at one moment in time.

Typical G-IV Flight path



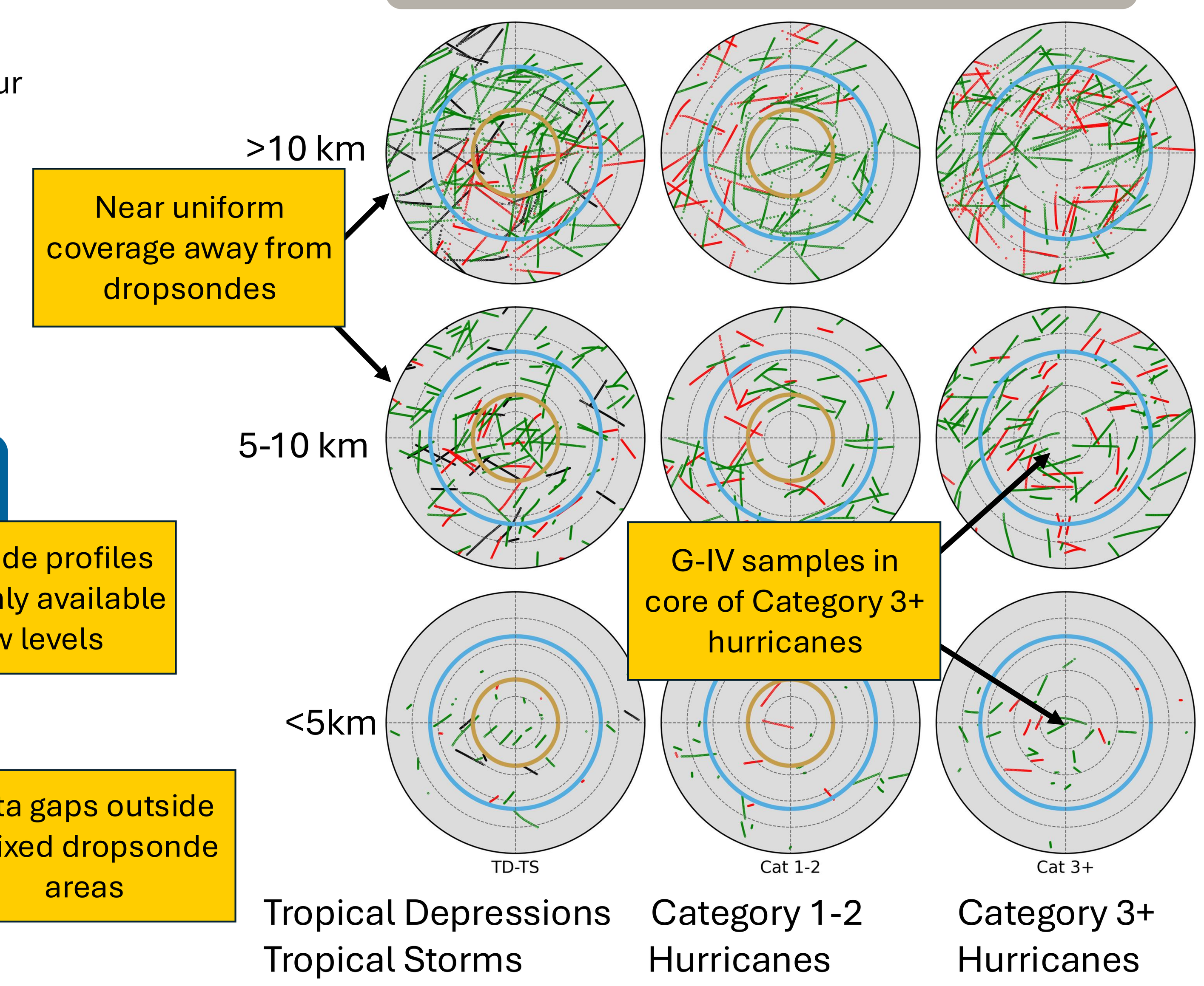
Typical dropsonde coverage (G-IV + C-130 + P-3)

Plan View Radial View



Adapted from Ditchek et. al. (2023)

G-IV ARO in 2022 storms Earl, Fiona and Ian



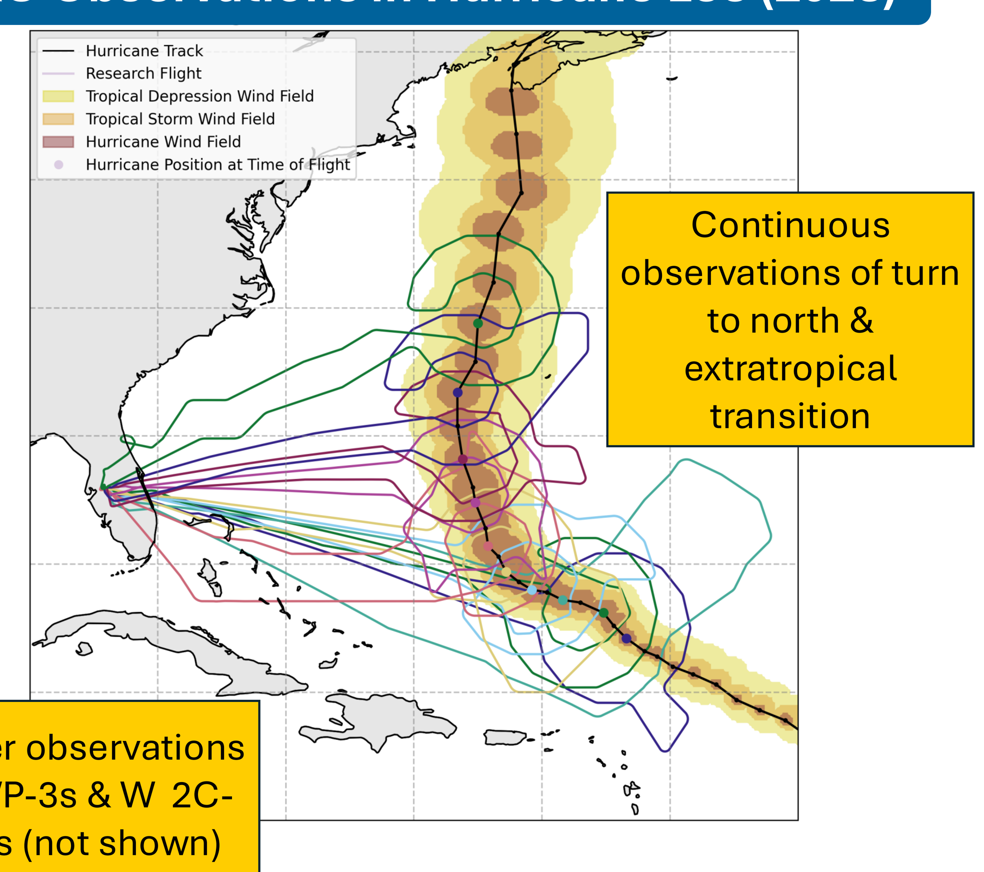
2237 ARO profiles in 17 named storms

- NOAA G-IV observations are high-altitude synoptic survey flights
- USAF WC-130 & NOAA WP-3 observations are lower-altitude flights into the TC core
- All G-IV flights into hurricanes for 2020 & 2022 season available at https://agsweb.ucsd.edu/gnss-aro/

ARO On NOAA G-IV, 2020-2023		
Season	Named Storm	ARO Profiles
2020	Isaias, Marco, Sally, Beta, Delta	522
2022	Earl, Fiona, Ian	639
2023	Hilary, Franklin, Idalia, Lee	>1022*
Grand Total		**2237**

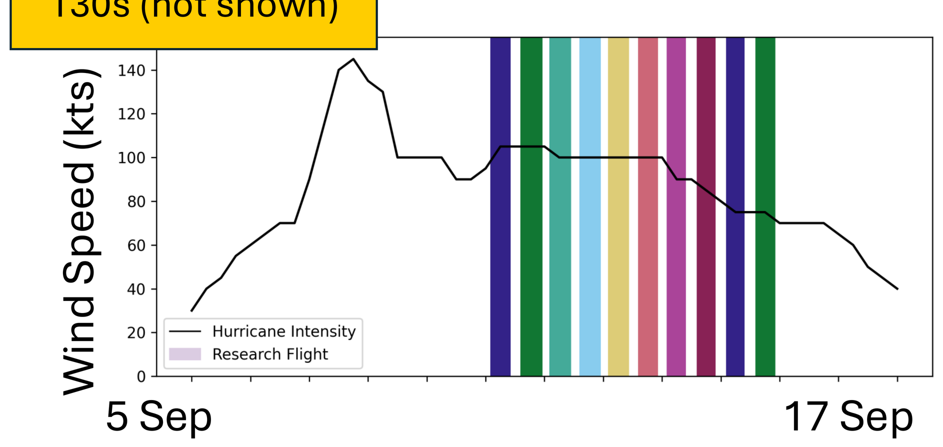
ARO on All Aircraft, 2024			
Named Storm	WC-130 Flights	WP-3 Flights	G-IV Flights
Alberto	1	0	0
Beryl	15	8	3
Debby	6	3	0
Ernesto	11	6	2
Hone	5	0	2
	38	**17**	**7**

ARO Observations in Hurricane Lee (2023)



Continuous observations of turn to north & extratropical transition

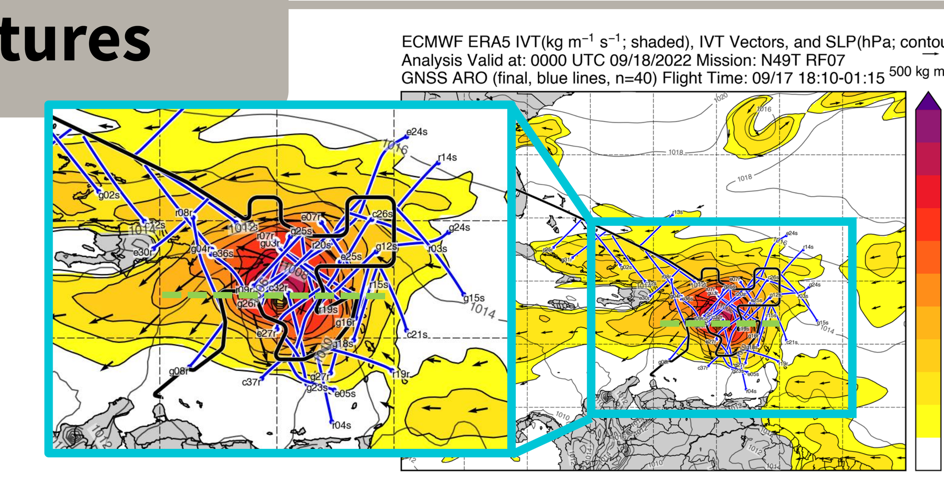
Earlier observations by WP-3s & W 2C-130s (not shown)



Evolution of ARO systems on research aircraft

- **2020**: ARO receiver deployed on NOAA G-IV N49RF for hurricane season
- **2023**: receivers deployed on NOAA G-IV, some USAF WC-130s & NOAA WP-3 N43RF
- **2024**: receivers deployed on NOAA G-IV, both WP-3s, all WC-130s, NASA ER-2
- **2025**: receivers deployed on NOAA G-IV, NOAA G550, both WP-3s, all WC-130s, NASA ER-2, NASA 777, DLR HALO

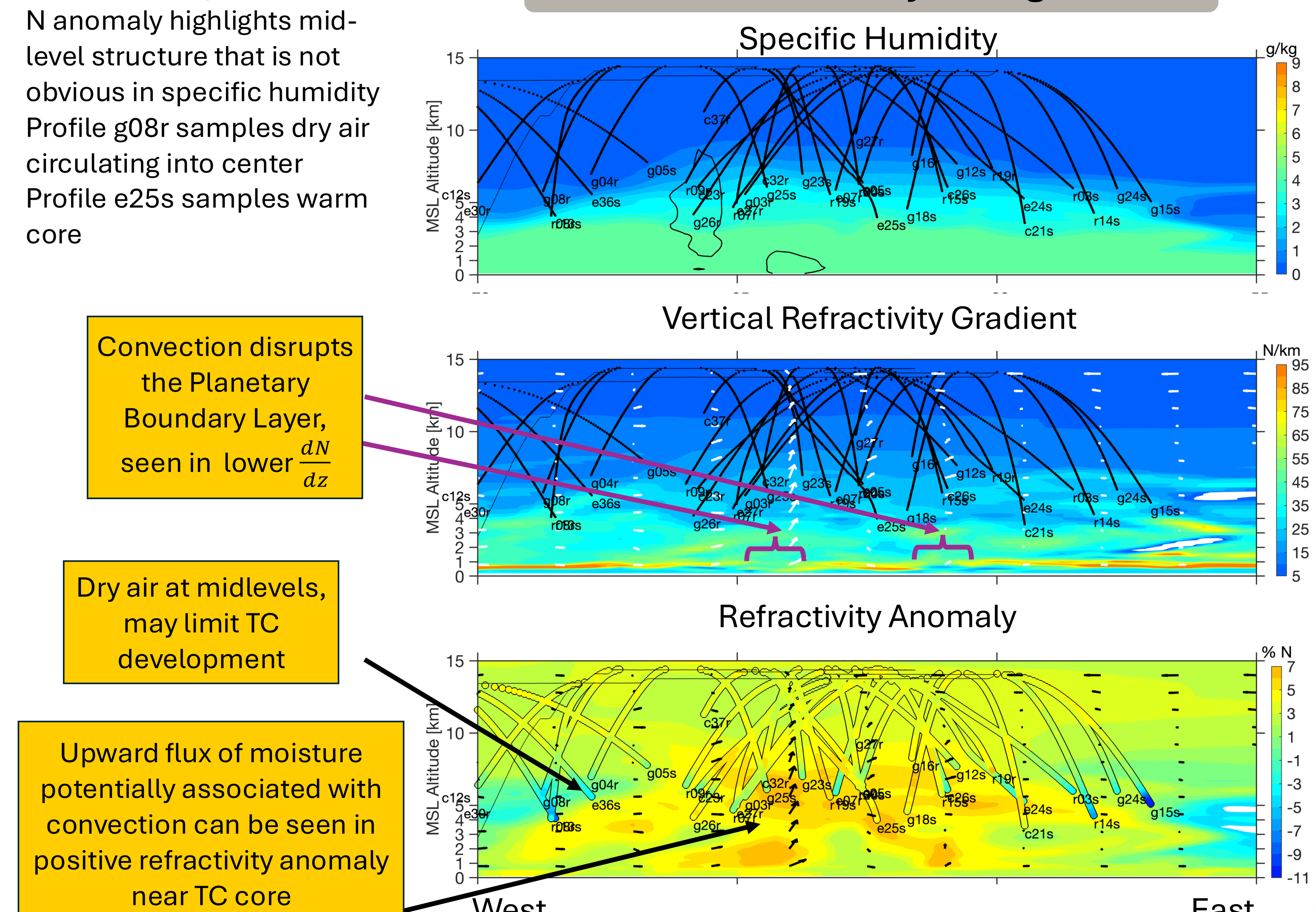
ARO Reveals Hurricane Structures



Transect of Hurricane Fiona using ARO collected from G-IV

- Refractivity (N) anomaly (lower panel) is difference between ERA5 refractivity and climatology
- N anomaly highlights mid-level structure that is not obvious in specific humidity
- Profile g08r samples dry air circulating into center
- Profile e25s samples warm core

Transect of refractivity through TC core



Conclusions

- G-IV samples mid-level tropical cyclone core structure while avoiding turbulence
- Refractivity anomaly can reveal vertical structure of storm
- 2237 ARO Profiles have been collected over 3 hurricane seasons
- Real-time processing and distribution are planned next season (Cao poster), low altitude observations are under development (Reinicke poster)

Acknowledgements

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Citations

- Cao, B., Haase, J. S., Murphy Jr., M. J., & Wilson, A. M. (2024). Observing atmospheric rivers using multi-GNSS airborne radio occultation: System description and data evaluation. https://doi.org/10.5194/amt-2024-119
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- Haase, J. & Murphy, M. & Cao, B. & Ralph, Fred & Zheng, Minghua & Monache, L.. (2021). Multi-GNSS Airborne Radio Occultation Observations as a Complement to Dropsondes in Atmospheric River Reconnaissance. Journal of Geophysical Research: Atmospheres. 126. 10.1029/2021JD034865.