Potential for PRO from Aircraft in Tropical Cyclones

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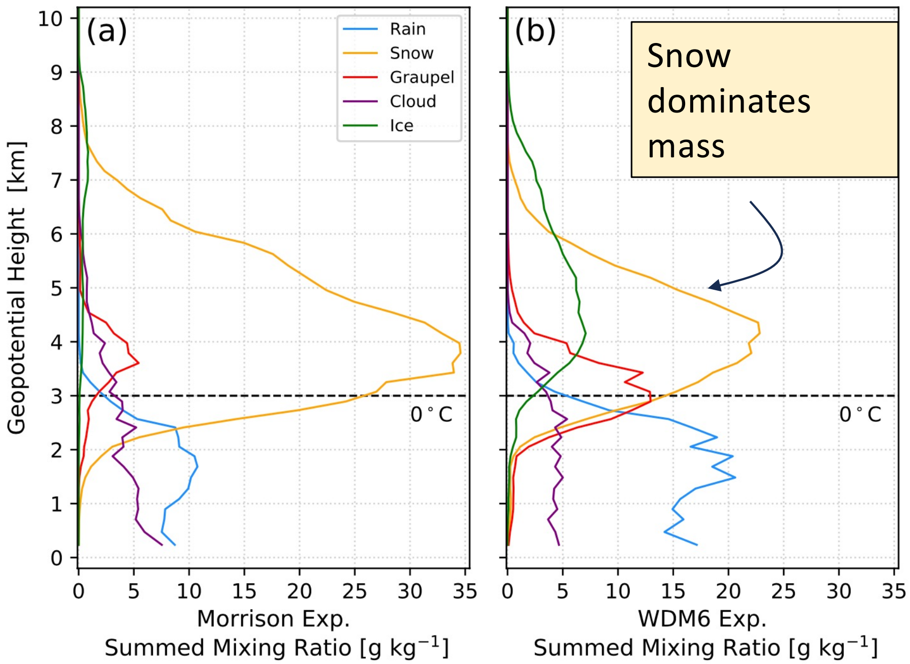
SCRIPPS INSTITUTION OF OCEANOGRAPHY

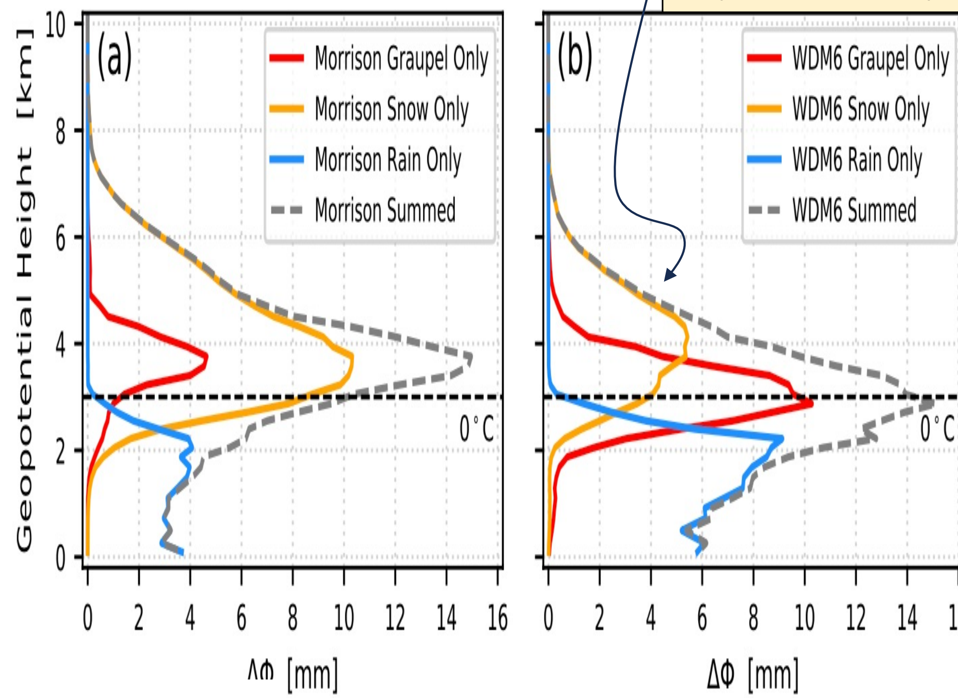
ARO PRO demonstration

- The seminal paper proposing RO as a technique to validate microphysical models demonstrated the concept with ARO (Murphy, et al., 2019)
- Targeted observations provide many more opportunities for verification
- They are preferentially in areas where microphysics plays an important role in the dynamics/forecasting
- The distribution of hydrometeors in the upper levels of hurricanes varies from graupel, supercooled drops, columns and aggregated snow depending on vertical motion, convective versus non-convective regions (Black & Hallet, 1985)
- Piggyback datasets have been collected in TCs where a large precip signal would represent an opportunity for further analysis
- => ARO is the perfect testbed for theoretical microphysical investigations that can be exploited at scale for GNSS RO as constellations grow in size.

Goal is to describe bulk parameter behavior

Snow less relative importance in dphi





$$K_{dp} = 10^{-3} \left(\frac{180}{\lambda}\right) C\rho_x IWC\,(1 - r_x) \quad (9)$$

where ρ_x is the particle density of the given hydrometeor x in g cm^{-3}, r_x is its axis ratio, C ~1.6 for Rayleigh scattering, and IWC is in g m^{-3}. We use ρ_{snow} = 0.1 and r_{snow} = 0.6, and $\rho_{graupel}$ = 0.3 and $r_{graupel}$ = 0.8, and we assume the effect of cloud ice with axis ratio near 1 is small and can be

Murphy et al., 2019, Atmospheres, described ARs, effects may be even more significant in TCs.

Interesting storms from 2023 Season

- Major Hurricane Franklin
- Major Hurricane Idalia
- Major Hurricane Lee

Examples of storms recorded in 2023 with ARO / PRO data illustrate the potential coverage.

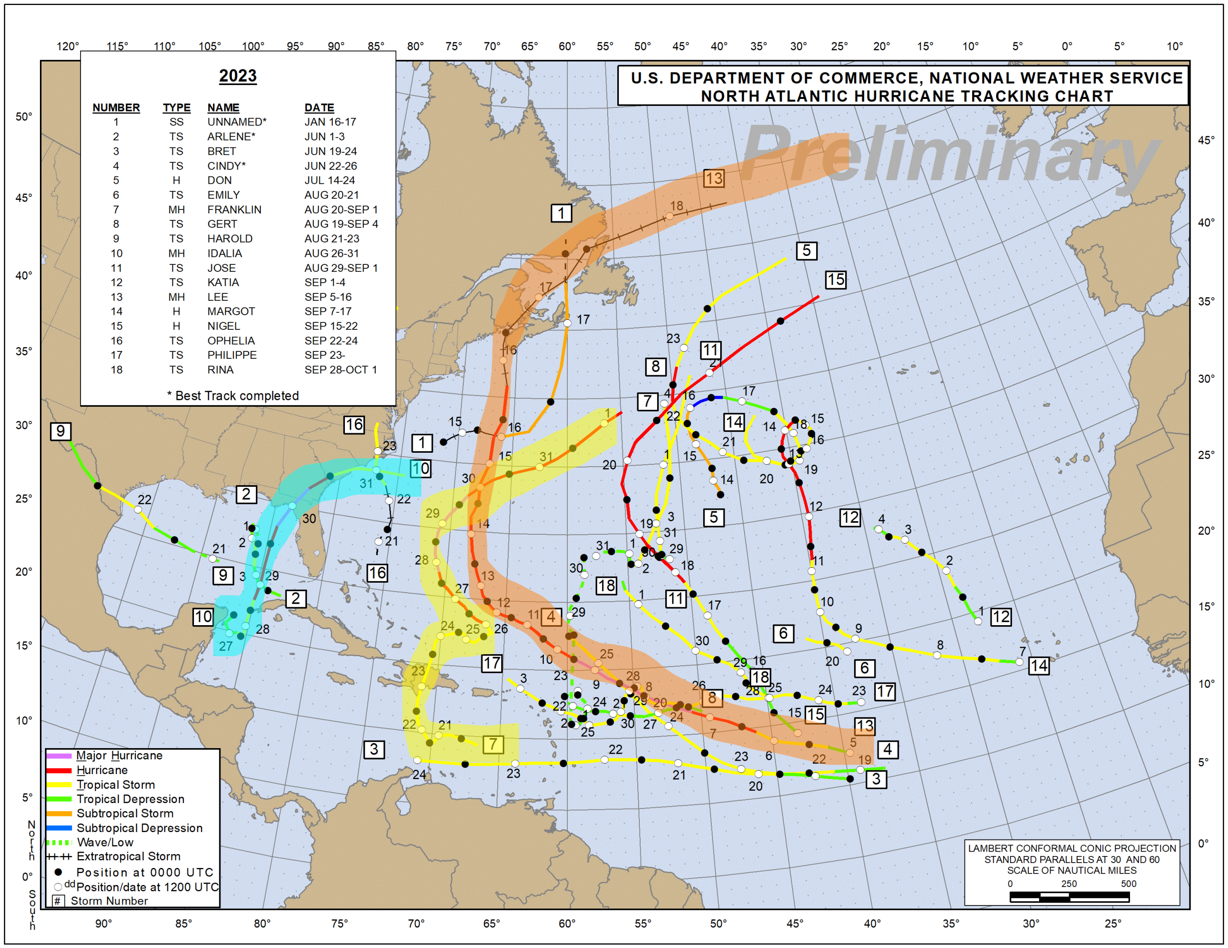
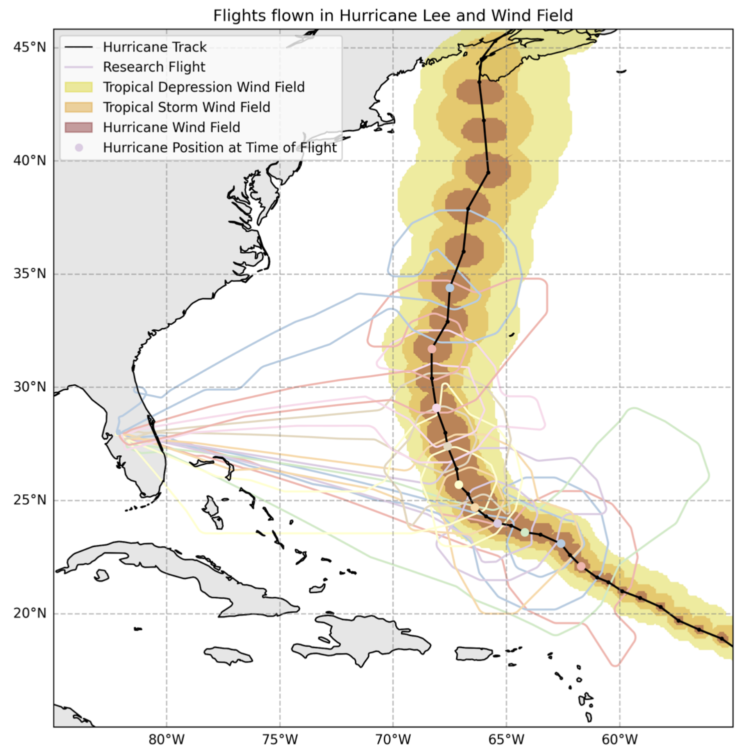
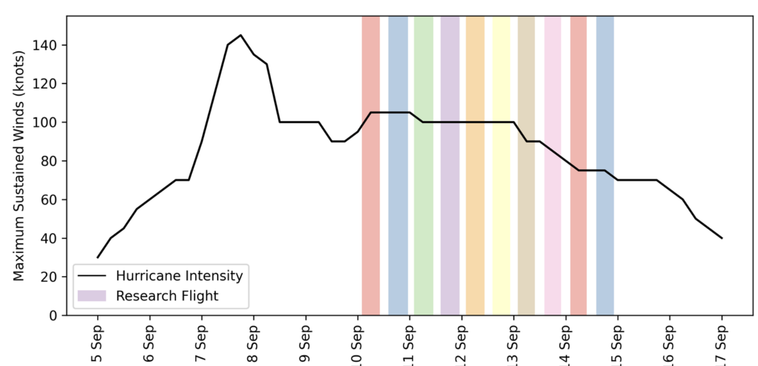


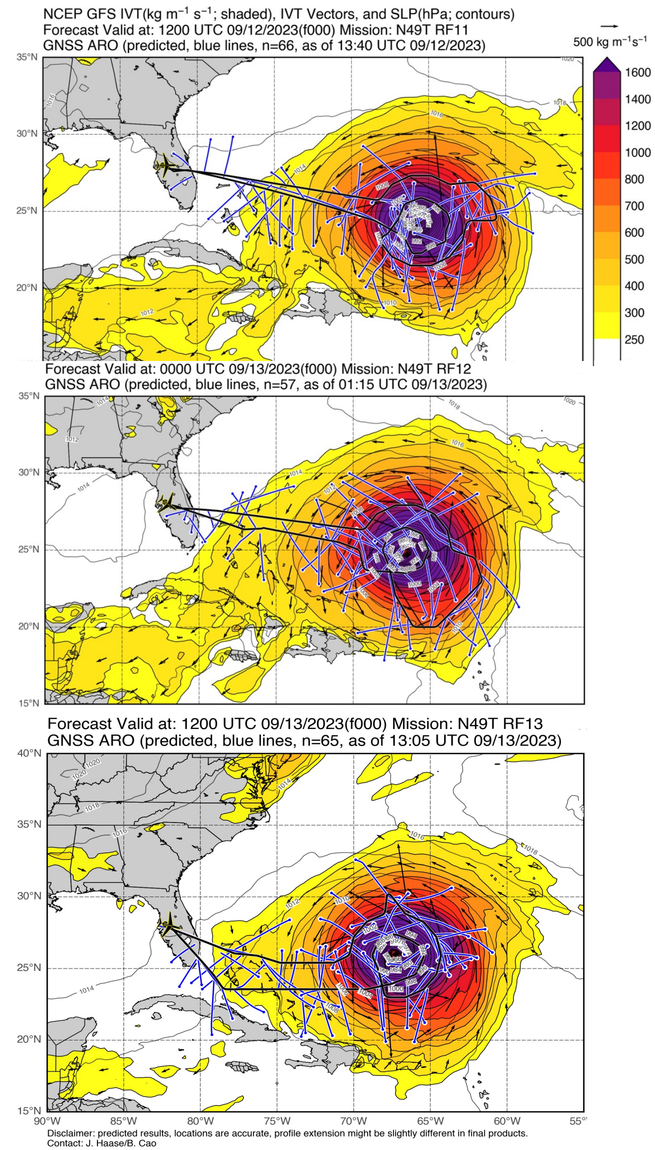
Figure modified from NHC

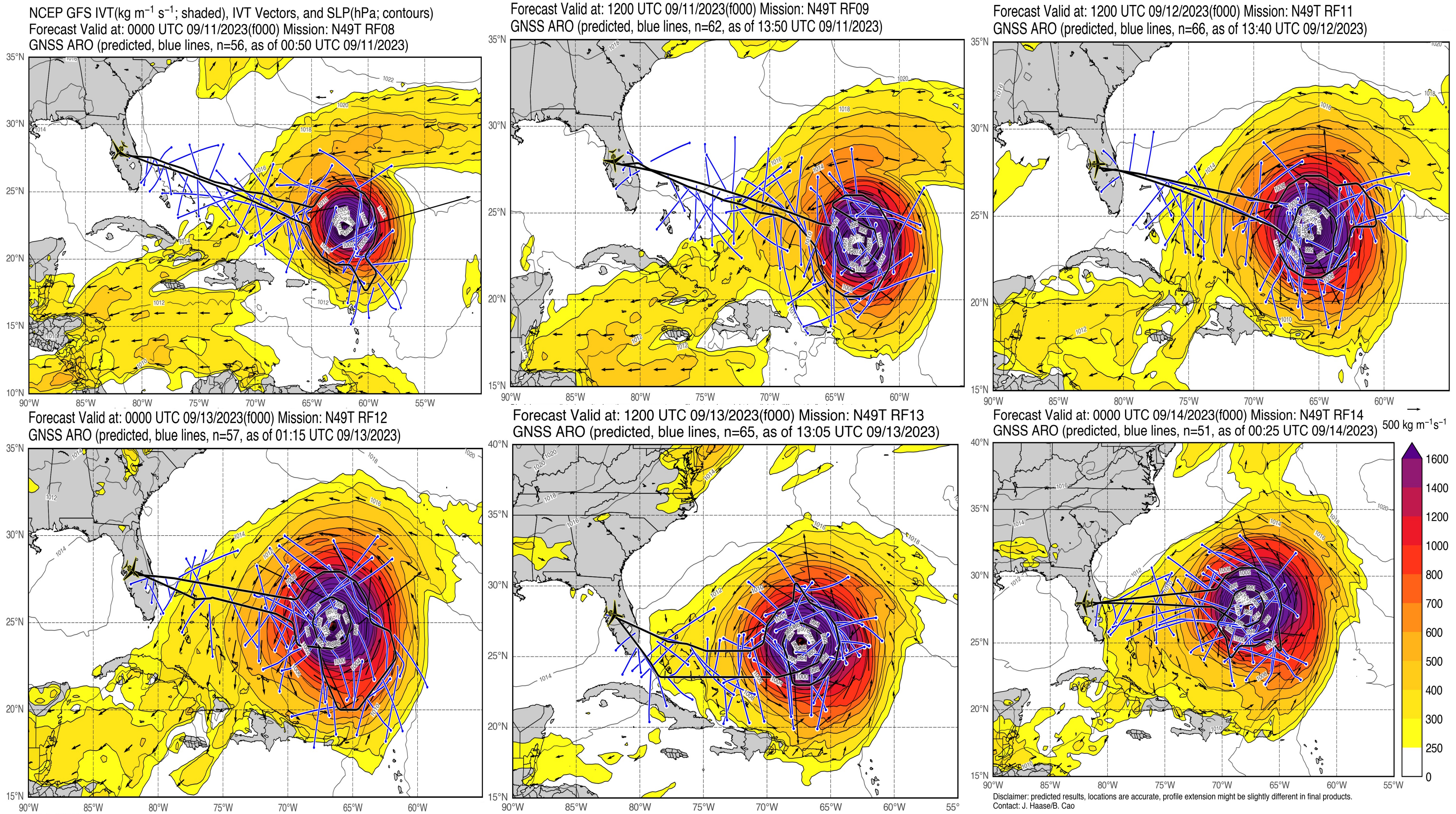
Excellent Coverage of Hurricane Lee

- NOAA G-IV flew 10 synoptic survey missions 14km flight level, 7 C-130 missions, some number of P-3 flights
- Observations as Lee turned north and during extratropical transition
- 53 flight hours and 419 predicted occultations from 10 research flights on the G-IV
- ideal candidate to evaluate the impact of ARO on forecast accuracy








NCEP GFS IVT(kg m^{-1} s^{-1}; shaded), IVT Vectors, and SLP(hPa; contours)
Forecast Valid at: 0000 UTC 09/11/2023(f000) Mission: N49T RF08
GNSS ARO (predicted, blue lines, n=56, as of 00:50 UTC 09/11/2023)
Forecast Valid at: 1200 UTC 09/11/2023(f000) Mission: N49T RF09
GNSS ARO (predicted, blue lines, n=62, as of 13:50 UTC 09/11/2023)
Forecast Valid at: 1200 UTC 09/12/2023(f000) Mission: N49T RF11
GNSS ARO (predicted, blue lines, n=66, as of 13:40 UTC 09/12/2023)
Forecast Valid at: 0000 UTC 09/13/2023(f000) Mission: N49T RF12
GNSS ARO (predicted, blue lines, n=57, as of 01:15 UTC 09/13/2023)
Forecast Valid at: 1200 UTC 09/13/2023(f000) Mission: N49T RF13
GNSS ARO (predicted, blue lines, n=65, as of 13:05 UTC 09/13/2023)
Forecast Valid at: 0000 UTC 09/14/2023(f000) Mission: N49T RF14
GNSS ARO (predicted, blue lines, n=51, as of 00:25 UTC 09/14/2023)
500 kg m^{-1}s^{-1}
1600
1400
1200
1000
800
700
600
500
400
300
250
0
Disclaimer: predicted results, locations are accurate, profile extension might be slightly different in final products.
Contact: J. Haase/B. Cao

Preliminary Results from 2023 Hurricane Season

Date	Storm	Aircraft	G	R	E	Rising	Setting	Total	Flight Hours	Number per hour	Interval
5-Aug	ferry	G-IV	5	6	6	8	9	17	3.5	4.9	12.2
6-Aug	Tropical wave	G-IV	22	18	19	30	29	59	7.7	7.7	7.8
7-Aug	Tropical wave	G-IV	18	21	15	27	27	54	7.7	7	8.6
9-Aug	ferry	G-IV	12	7	6	10	15	25	4	6.2	9.7
18-Aug	Hilary	WC-130	43	27	21	40	51	91	9.2	9.9	6.1
18-Aug	Hilary	WC-130	45	34	27	52	54	106	9.7	10.9	5.5
19-Aug	Hilary	WC-130	30	20	19	30	39	69	7.4	9.3	6.5
20-Aug	Hilary	WC-130	35	25	21	36	45	81	8.3	9.8	6.1
22-Aug	Franklin	G-IV	19	17	13	24	25	49	7.2	6.8	8.8
28-Aug	Idalia	G-IV	19	18	15	26	26	52	6.5	8	7.5
10-Sep	Lee	G-IV	22	17	19	26	32	58	7.6	7.6	7.9
11-Sep	Lee	G-IV	26	19	18	32	31	63	8.3	7.6	7.9
11-Sep	Lee	G-IV	26	22	18	32	34	66	8.1	8.1	7.4
11-Sep	Lee	G-IV	26	17	17	29	31	60	8	7.5	8
13-Sep	Lee	G-IV	23	24	19	32	34	66	7.6	8.7	6.9
13-Sep	Lee	G-IV	24	12	16	24	28	52	7.2	7.2	8.3
14-Sep	Lee	G-IV	18	18	18	26	28	54	7.1	7.6	7.9
			413	322	287	484	538	1022	125.1	7.9	7.8

From PAZ Workshop on Tuesday

Ben Johnston

HAFS: GNSS-RO Impact Assessment

Time period: 2022 Atlantic Hurricane Season

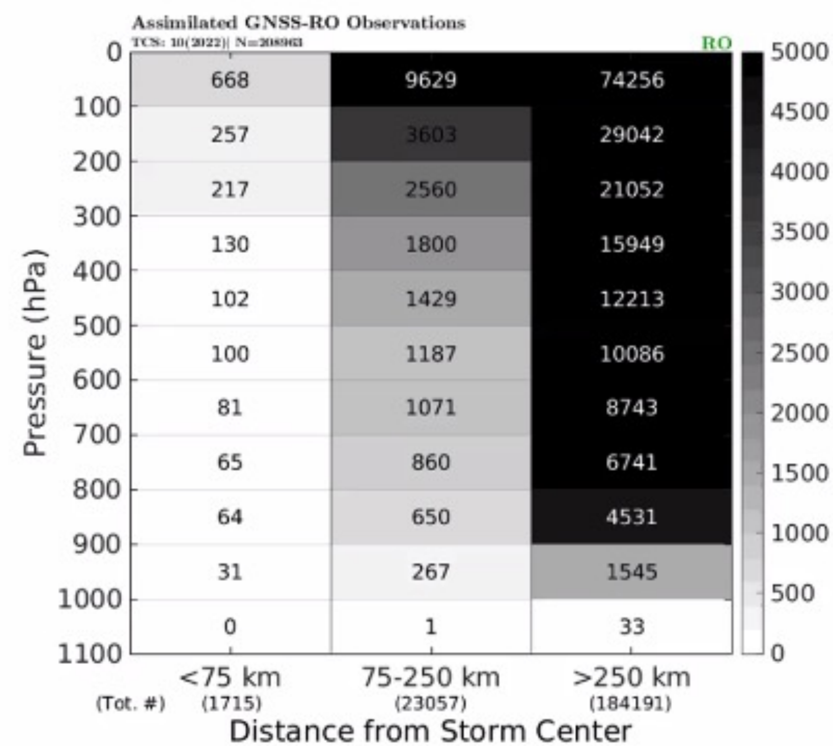
Sample size: 10 tropical cyclones (TCs), mostly reaching hurricane strength

Model: HAFS-A v1 (current operational setup)

Control: "NoRO" - all RO data denied in both the GFS (used for ICs and BCs) and HAFS

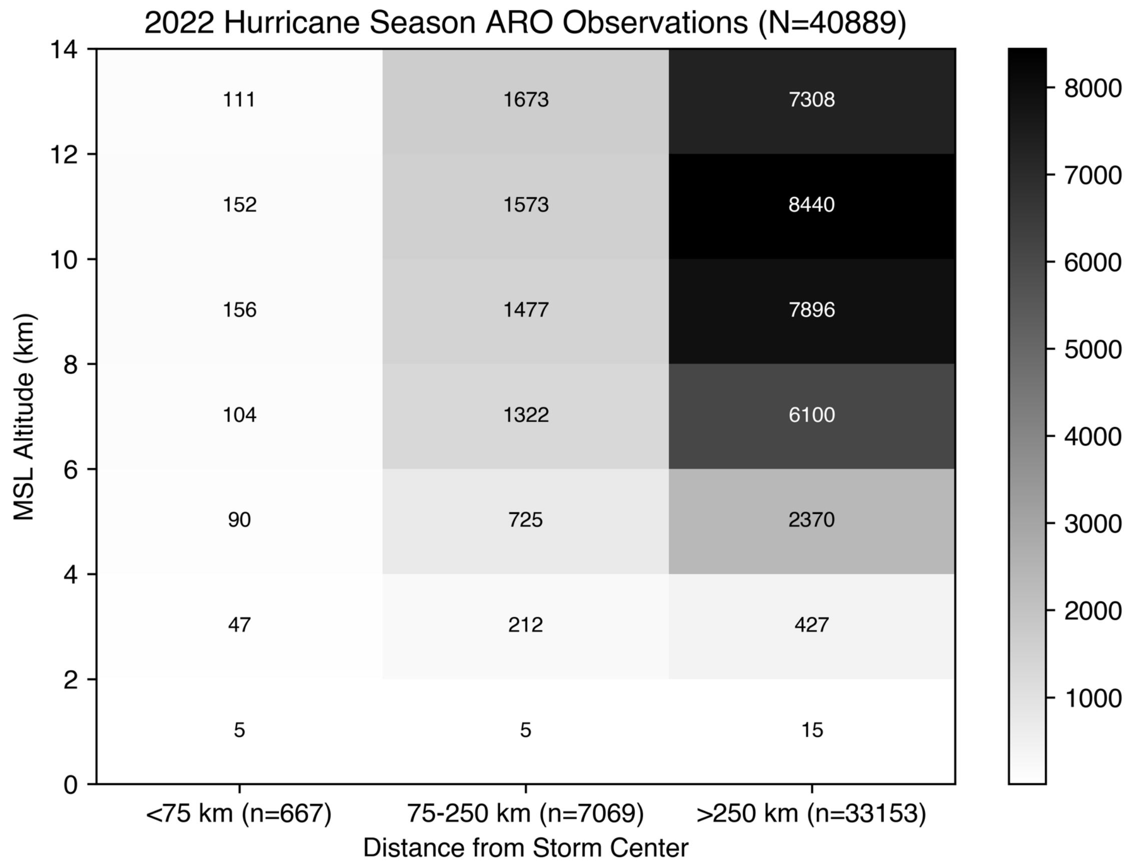
Experiment: "RO" - all available RO data is assimilated in GFS and HAFS

- In the HAFS inner moving nest (where DA occurs), most RO bending angle obs are assimilated in the **synoptic environment**, with only a small percentage in the TC inner core



Analogous Slide from TC22 ARO

- Time period: 2022 Atlantic Hurricane season
- Sample size: 3 named storms from 12 flights
- Counts represent each tangent point observation, a profile consists of many tangent points
- These are total obs, not assimilated obs
- Can convert y axis to pressure if interested (14km = 150hPa, 10km = 250hPa, 5.5km = 500hPa)



Potential PRO/ARO complementarity

- Can we propose ARO as a testbed for theoretical microphysical investigations
- Many observations near the TC center
- Results can be exploited at scale for GNSS RO as constellations grow in size.

- Future seasons:
- Opportunity for collaborations, esp to advance antenna technology
- Opportunities for access to NOAA GIV, P-3, or other NASA aircraft
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