The Impact of Assimilating GNSS-RO Observations on HAFS Tropical Cyclone Forecasts from the 2022 Atlantic Hurricane Season

Benjamin Johnston [1,2] (benjamin.johnston@noaa.gov), Lidia Cucurull [2], and Richard Anthes [1]

[1] University Corporation for Atmospheric Research [2] NOAA Quantitative Observing System Assessment Program

INTRODUCTION

- Previous studies have shown that assimilating GNSS-RO bending angle (BA) observations in regional tropical cyclone (TC) models can produce improvements to TC forecasts
  - Notable when conventional soundings are limited
  - Improves large-scale temperature, moisture, and wind fields
- An unprecedented number of high vertical resolution RO profiles are now available for assimilation due to the launch of COSMIC-2 (C2) along with commercial RO sources such as Spire
  - Spire retrieval accuracies/depths are comparable to C2

Main Research Goals

(1) To quantify the impact that assimilating RO BA profiles has on TC track and intensity forecasts in the Hurricane Analysis and Forecasting System (HAFS) model

(2) To determine the relative value of assimilating C2 and Spire BAs in the HAFS inner domain

HAFS BACKGROUND

- Developed by NOAA and partners; became operational in 2023
- Convection-allowing, high resolution, atmosphere-ocean-wave coupled TC forecasting system with vortex initialization, data assimilation (GSI-based), physics suite calibrated for hurricanes
- Parent domain: ~78°×75°, spatial resolution of 6 km; storm-following nested domain: ~12°×12°, 2 km spatial resolution
- 81 vertical levels with a model top of 2 mb
- GSI uses a local forward operator for computing RO BAs
- ~9,000 RO profiles/day were available for assimilation during the 2022 hurricane season (mainly from C2, Spire, and MetOp)

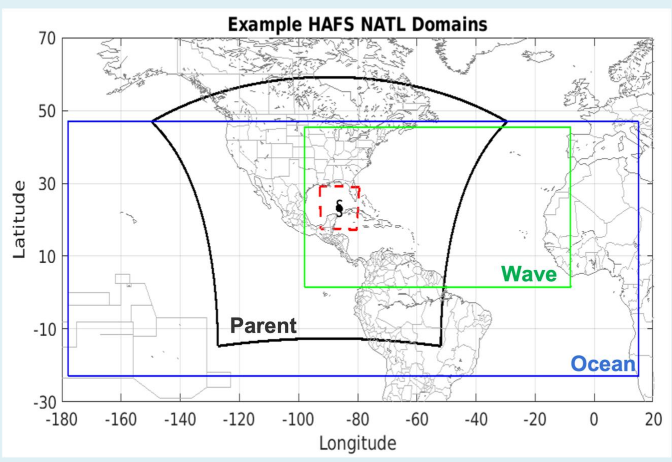

Figure 1. An example of the HAFS atmospheric (parent domain in black, nested domain in red), oceanic (blue), and wave (green) domains over the North Atlantic basin.

EXPERIMENT DESIGN

- Focused on the active 2022 Atlantic hurricane season
- Selected ten cases for study (Hurricanes Danielle, Earl, Fiona, Ian, Julia, Lisa, Martin, Nicole; Tropical Storms Gaston and Karl)
- A control and five experiments were conducted
  - Assimilation of RO BAs was either turned off ("No RO") or on ("RO") in the GFS (GFS output is used for ICs/BCs in HAFS)
  - Differing amounts of RO data were assimilated in HAFS
  - All ten TCs were run for each of the six experiments
- The consistency metric (Ditchek et al. 2023) was used to evaluate model performance (uses MAE, MDAE, and FSP)

Experiment	GFS	HAFS
1 ("NoRO"; Control)	No RO	No RO
2 ("NoROG-C2H")	No RO	C2 only
3 ("NoROG-SpireH")	No RO	Spire only
4 ("ROG-C2H")	RO	C2 only
5 ("ROG-SpireH")	RO	Spire only
6 ("RO")	RO	RO

Table 1. Summary of the six experiments conducted for this study.

TC CASES AND ASSIMILATED RO BAs

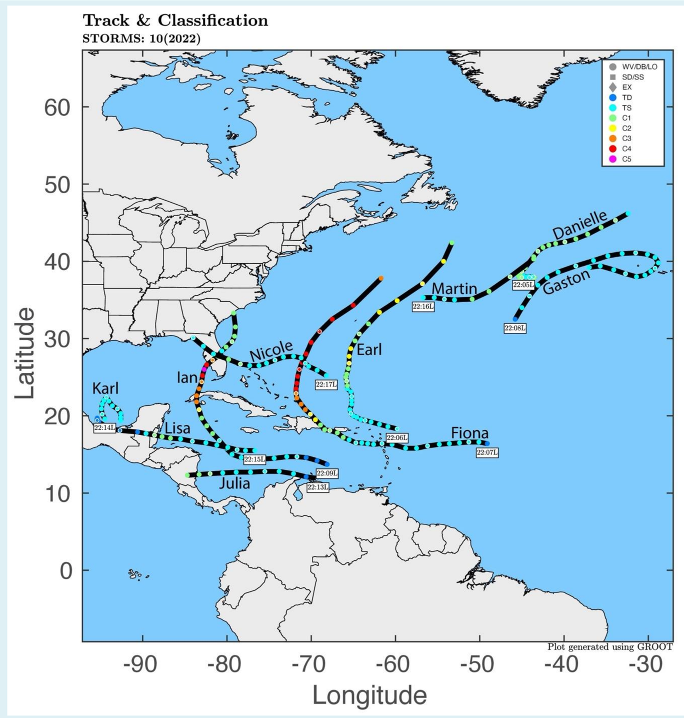

Figure 2. Tracks and intensities of the ten TCs from the 2022 Atlantic hurricane season selected for analysis in this study.

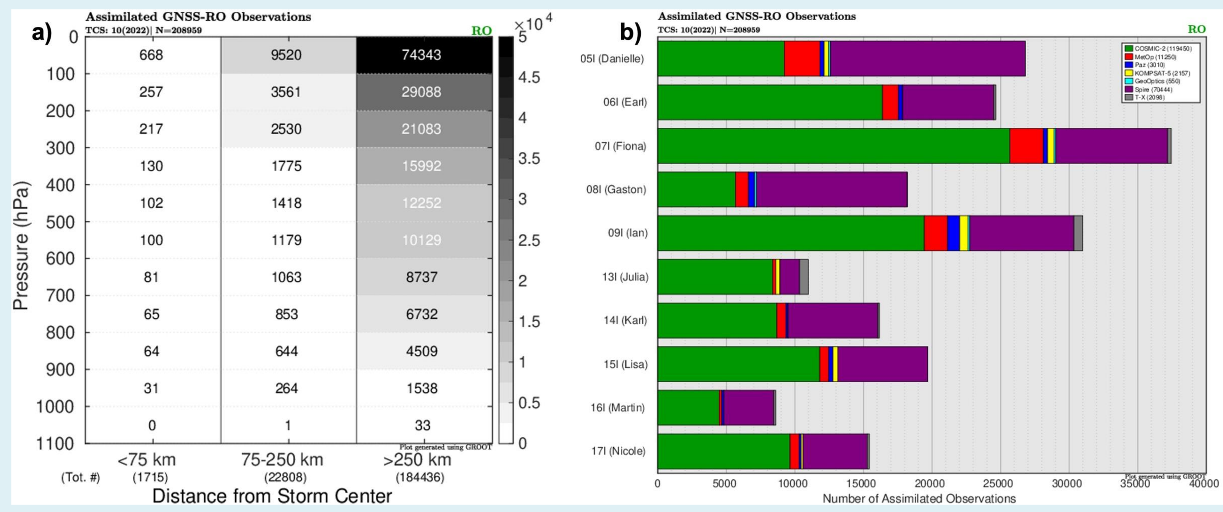

Figure 3. RO observations assimilated within HAFS in the "RO" experiment for a) different pressure levels using three distance intervals from the TC centers and b) the ten TCs categorized by each available RO mission.

COMPOSITE RESULTS

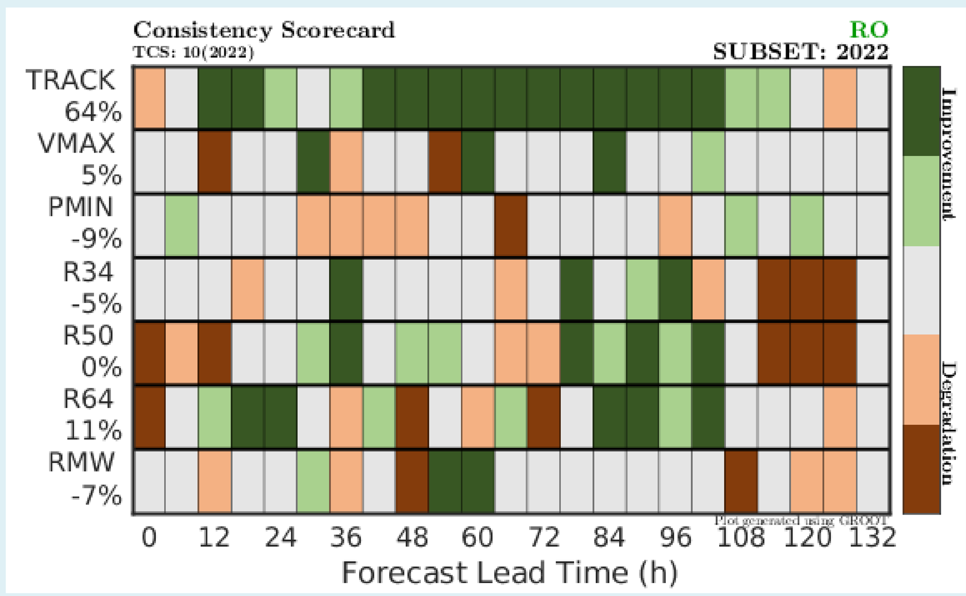

Figure 4. A consistency scorecard for the "RO" experiment showing the impact of RO observations on TC forecasts of track (TRK), maximum wind speed (VMAX), minimum central pressure (PMIN), and R34, R50, R64, and RMW (34-kt, 50-kt, 64-kt, and maximum wind radii), shown from top to bottom.

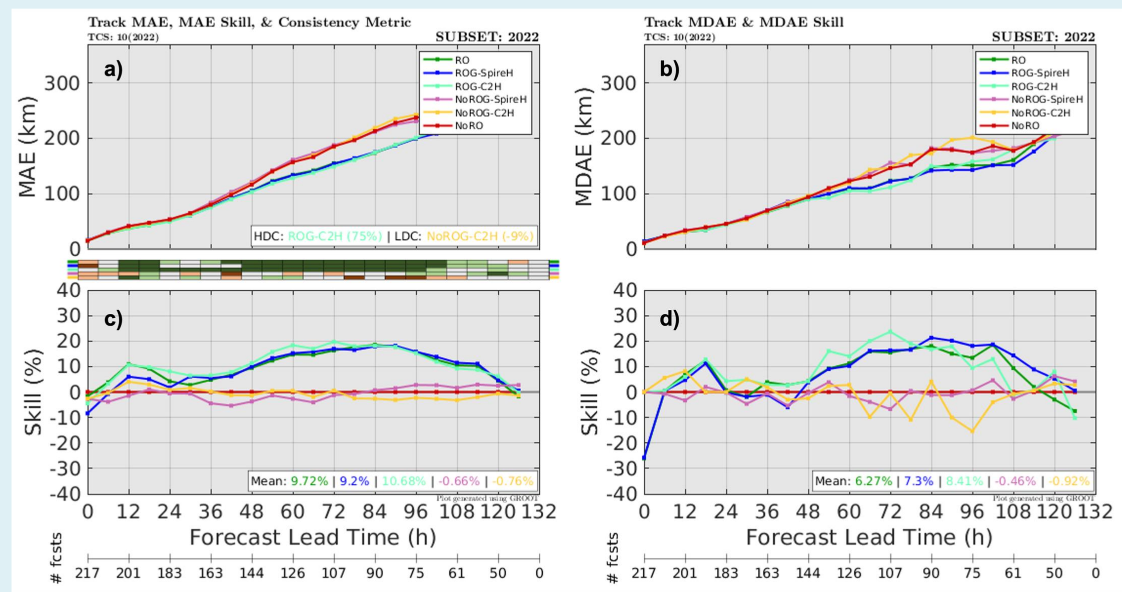

Figure 5. The impact of RO observations on TC track forecasts from the 2022 Atlantic hurricane season. Graphics include the (a,c) MAE and MAE skill, augmented with the consistency metric, and (b,d) MDAE and MDAE skill. The average skill value for each experiment across all lead times is given in the bottom right of the skill panels. The number of forecasts for each forecast lead time is shown at the bottom.

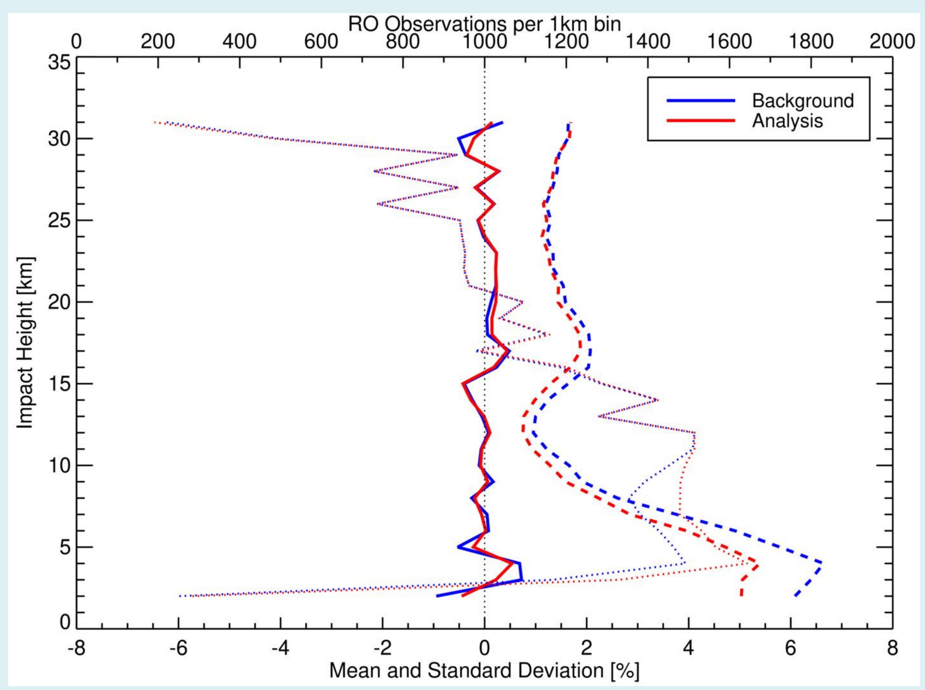

Figure 6. RO bending angle fractional innovation (e.g., [O-B]/B; blue) and analysis residuals (e.g., [O-A]/A; red) mean bias (solid lines) and standard deviation (dashed lines) profiles for RO observations assimilated by HAFS for Hurricane Ian. The number of observations in each impact height bin is denoted by the dotted lines.

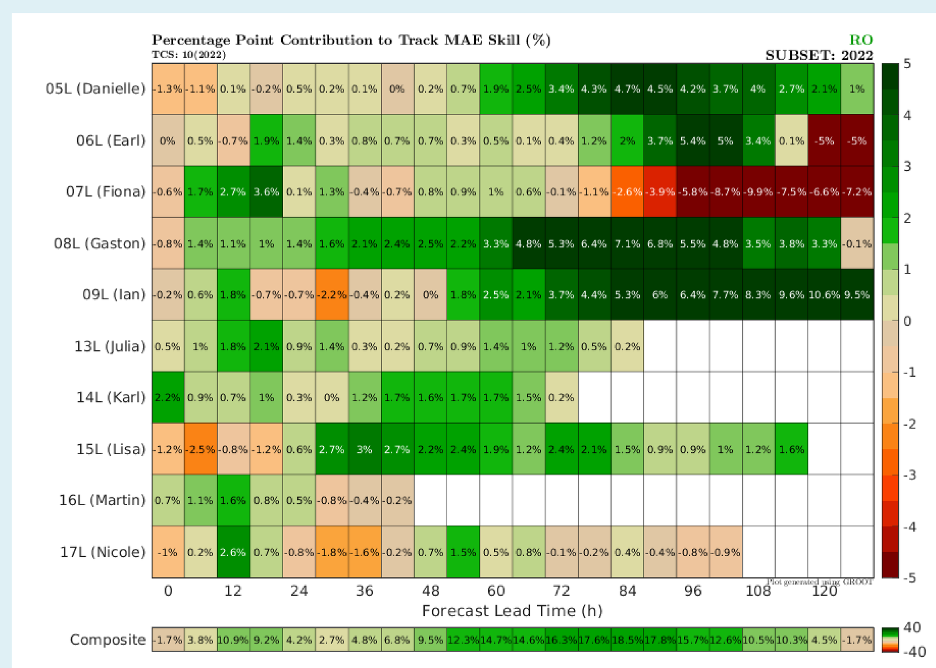

Figure 7. Percentage point contributions of each TC in the sample towards the composite track MAE skill at each forecast lead time.

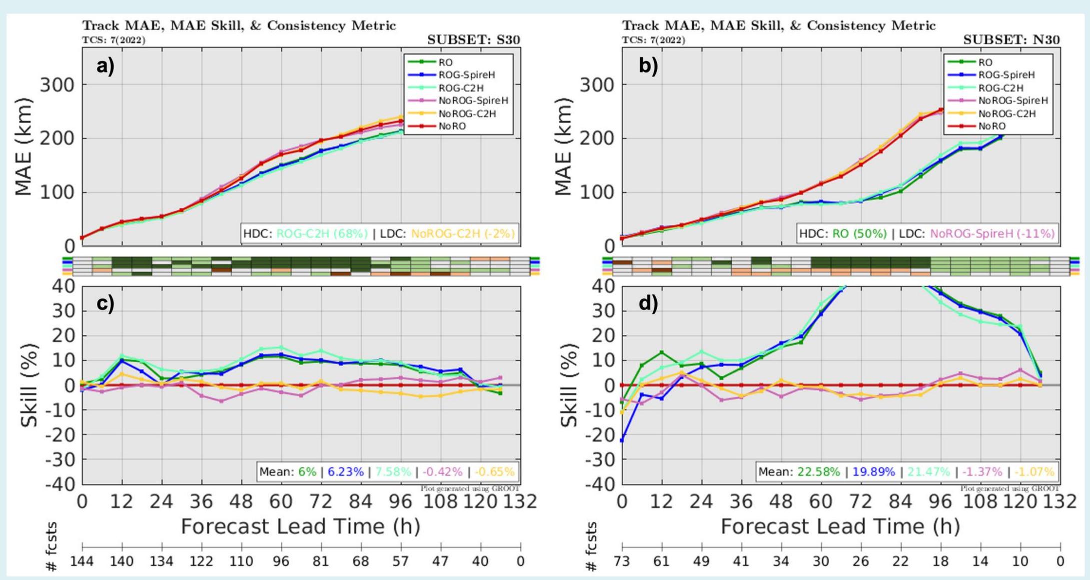

Figure 8. The impact of RO observations on TC track forecasts from the 2022 Atlantic hurricane season for TCs south of 30°N (left) and north of 30°N (right). The number of forecasts for each forecast lead time is shown at the bottom.

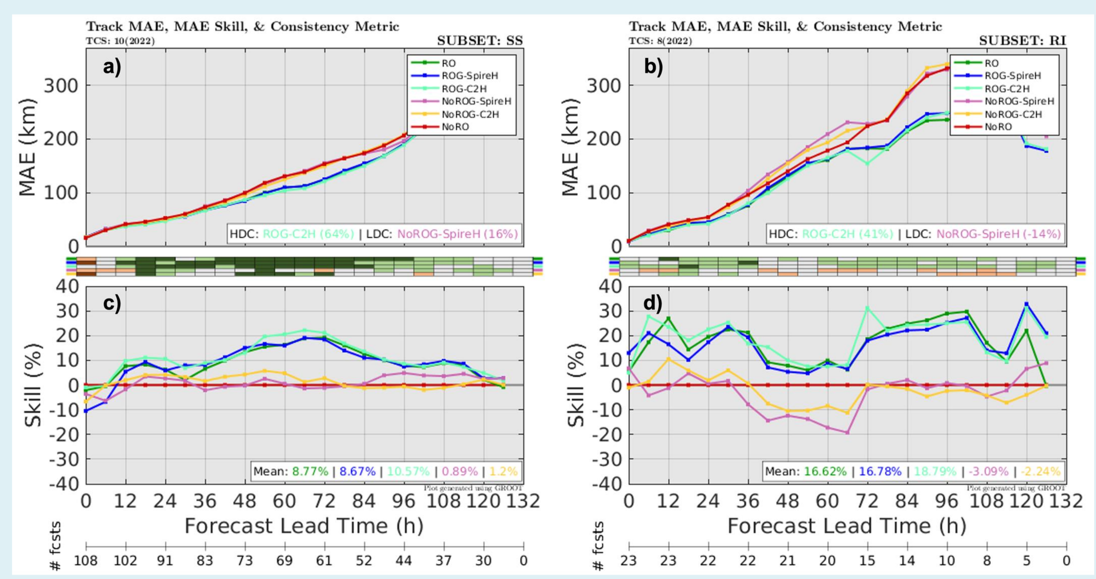

Figure 9. The impact of RO observations on TC track forecasts for TCs that are in a steady intensity state (left) or undergoing rapid intensification (right). The number of forecasts for each forecast lead time is shown at the bottom.

IAN CASE STUDY

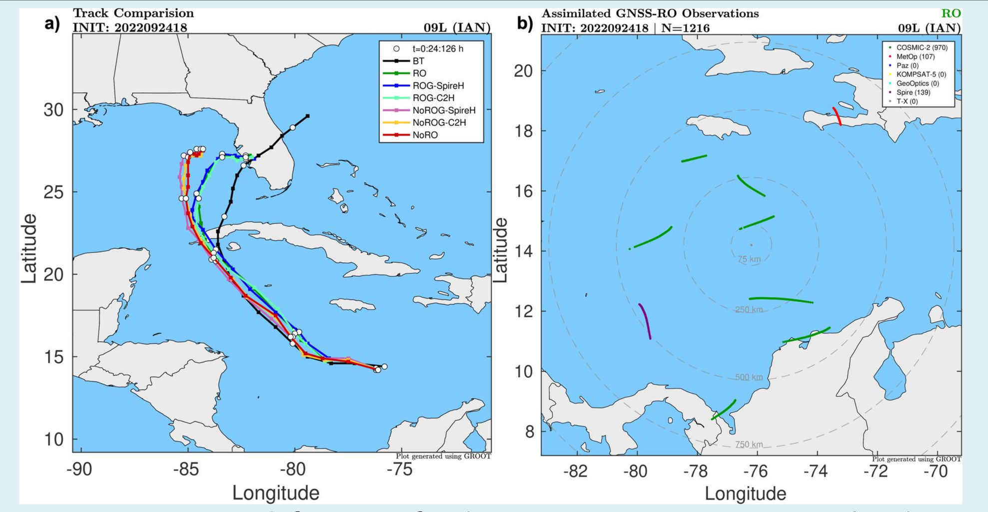

Figure 10. (a) Hurricane Ian track forecasts for the six HAFS experiments initialized on September 24 at 18 UTC. The location of the NHC's best track is also shown in black. (b) The location of RO observations (classified by RO mission) assimilated within the HAFS nested domain for this cycle.

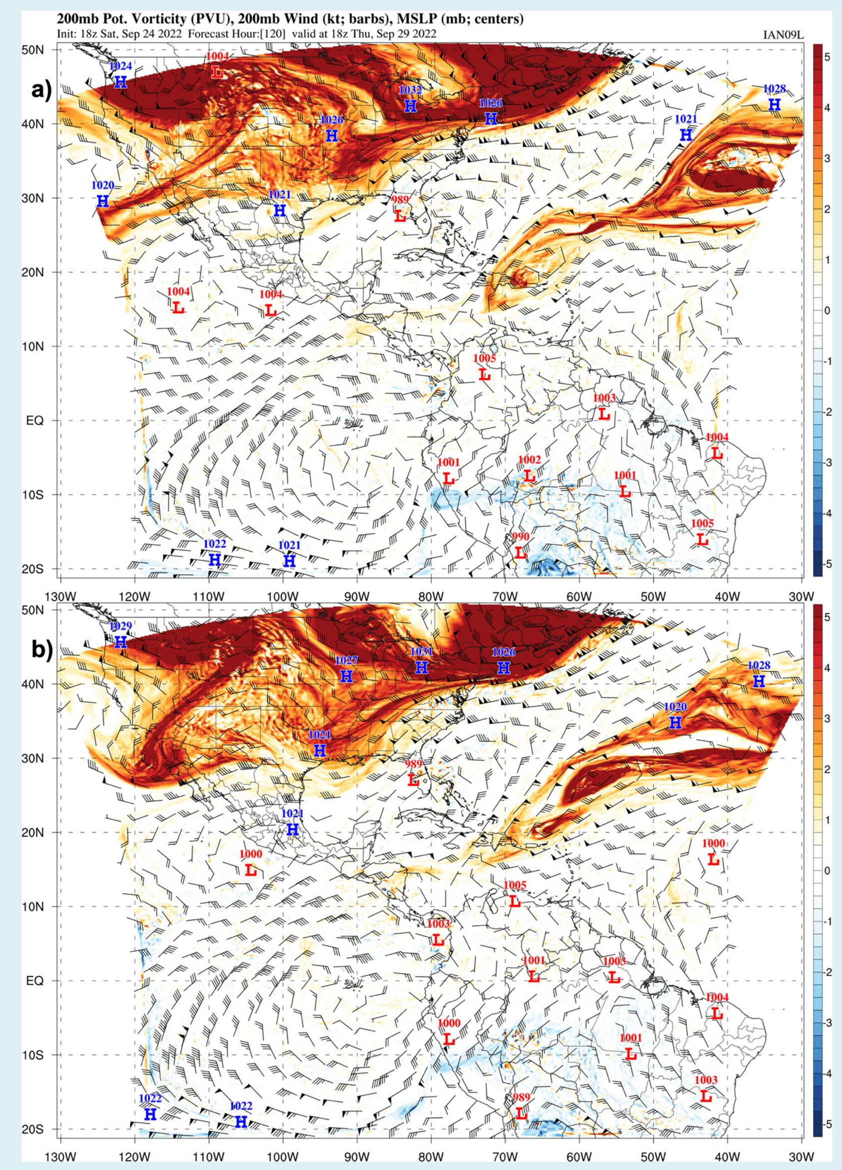

Figure 11. Maps of the 200 mb potential vorticity (PVU; colored contours) and winds (knots; barbs) along with mean sea level pressure centers within the HAFS parent domain for the (a) "No RO" and (b) "RO" experiments.

CONCLUSIONS

- Considerable track improvements were observed after RO data was assimilated within both the GFS and HAFS
  - Seen for almost all 10 TCs and at almost all lead times, steadily increasing and reaching a maximum of ~15-20% at day 3-4
  - Track improvements were mainly from assimilating RO in the GFS, as improvements were very similar for the three different experiments that assimilated RO in the GFS
  - TCs in the midlatitudes displayed much larger skill improvements (>40%) relative to TCs in the tropics
  - TCs undergoing RI had track MAE skill improvements at all lead times (were considerably larger than steady-state TCs)
- Mixed results for the other TC forecast metrics - assimilation of RO data provides minimal benefit to forecasting TC intensity (likely because few RO BAs assimilated near TC inner core)
- Track forecasts for Hurricane Ian showed exceptional improvements after assimilating RO data during earlier cycles
  - RO helped produce a more robust synoptic-scale wave pattern over the U.S., steering Ian towards the western Florida coast

ACKNOWLEDGEMENTS

This work was funded by NESDIS/OSAAP/CWD and conducted under the NOAA Quantitative Observing System Assessment Program (QOSAP). Benjamin Johnston was funded by the NOAA Cooperative Agreement NA21OAR4310473. Thanks to Dr. Michael Mueller for conducting the two GFS runs used in this study. The GRaphics for OS(S)Es and Other modeling applications on TCs (GROOT) verification package developed by Dr. Sarah Ditchek and funded by QOSAP and the FY18 Hurricane Supplemental (NOAA Award ID #NA19OAR0220188) was used to generate graphics for this work. Additionally, the Graphical Post-processed Locus for Output of Tropical cyclones (GPLOT) verification package developed by Dr. Ghassan Alaka (https://github.com/ghassan-alaka/GPLOT) was used to generate graphics for this work.