Does Assimilating PlanetIQ and Spire GNSS RO Bending Angles Improve HAFS Forecasts of Four 2022 Atlantic Hurricanes? An Evaluation in Support of the ROMEX Experiment

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Outline

I) HAFS Model Description and Experiment Design

II) PlanetiQ and Spire **observation error diagnostics**

III) PlanetiQ and Spire data assimilation impacts on HAFS **hurricane track and intensity forecast errors**

IV) PlanetiQ and Spire data assimilation impacts on HAFS **temperature and water vapor** errors

V) Concluding Remarks

HAFS Model Description

- As of 2023, HAFS-A and HAFS-B have replaced the HWRF and HMON as NOAA's operational regional TC forecasting models
- This study uses a developer configuration of HAFS-A *v2* resembling the 2024 operational HAFS-A
- Key HAFS-A *v2* features:

➢ **GSI 4DEnVar** data assimilation using background error covariances from the 80-member GEFS

➢ **Assimilates in-situ recon mission observations** such as dropsondes and P-3 TDR winds

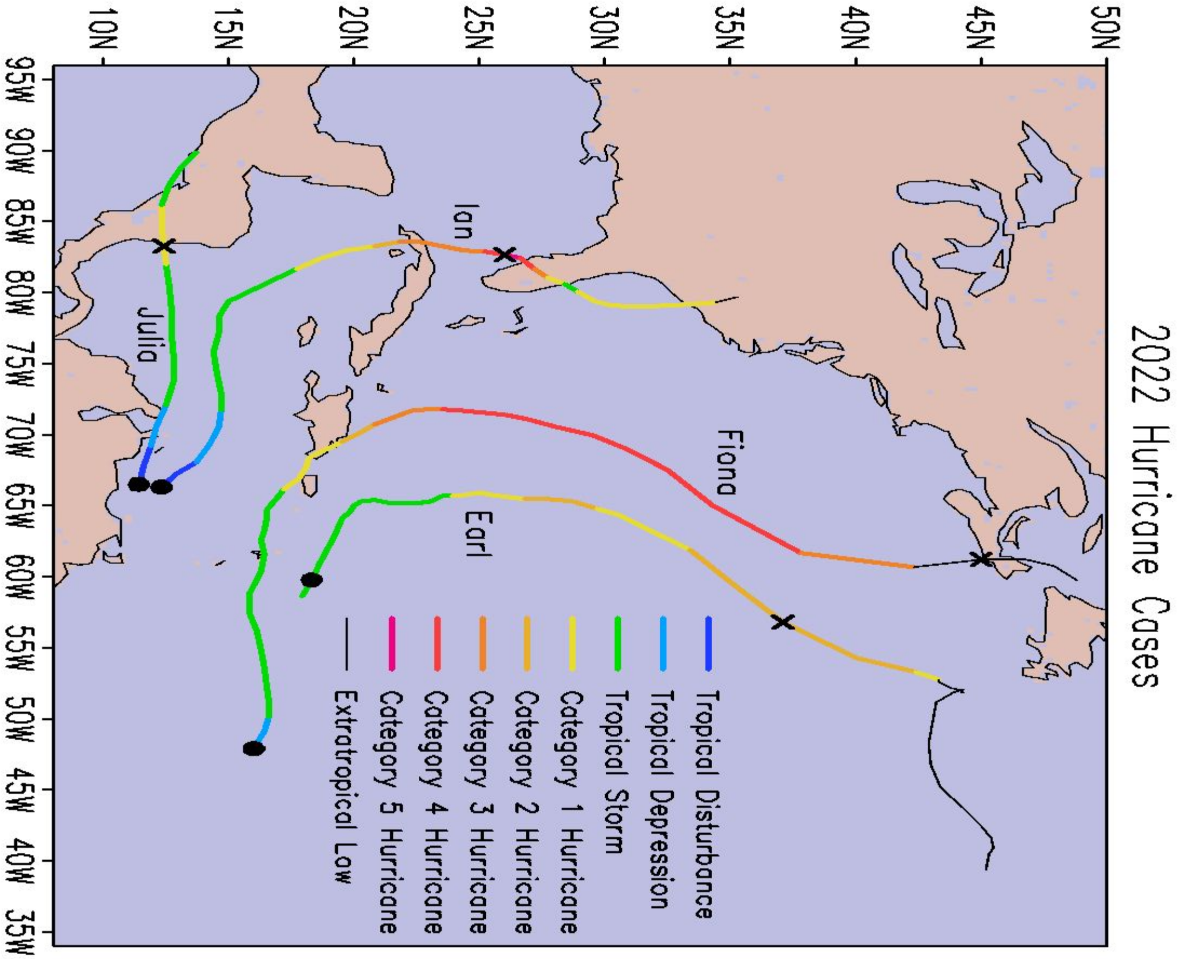
➢ Assimilates GNSS RO bending angles using **NOAA's 1D NBAM forward operator**

➢ **Cycled DA** every 6 hours

➢ **Vortex relocation/improvement** prior to DA

➢ ~ **1.8 km horizontal resolution** in a 12° × 12° sized storm-following nest

Experiment Design

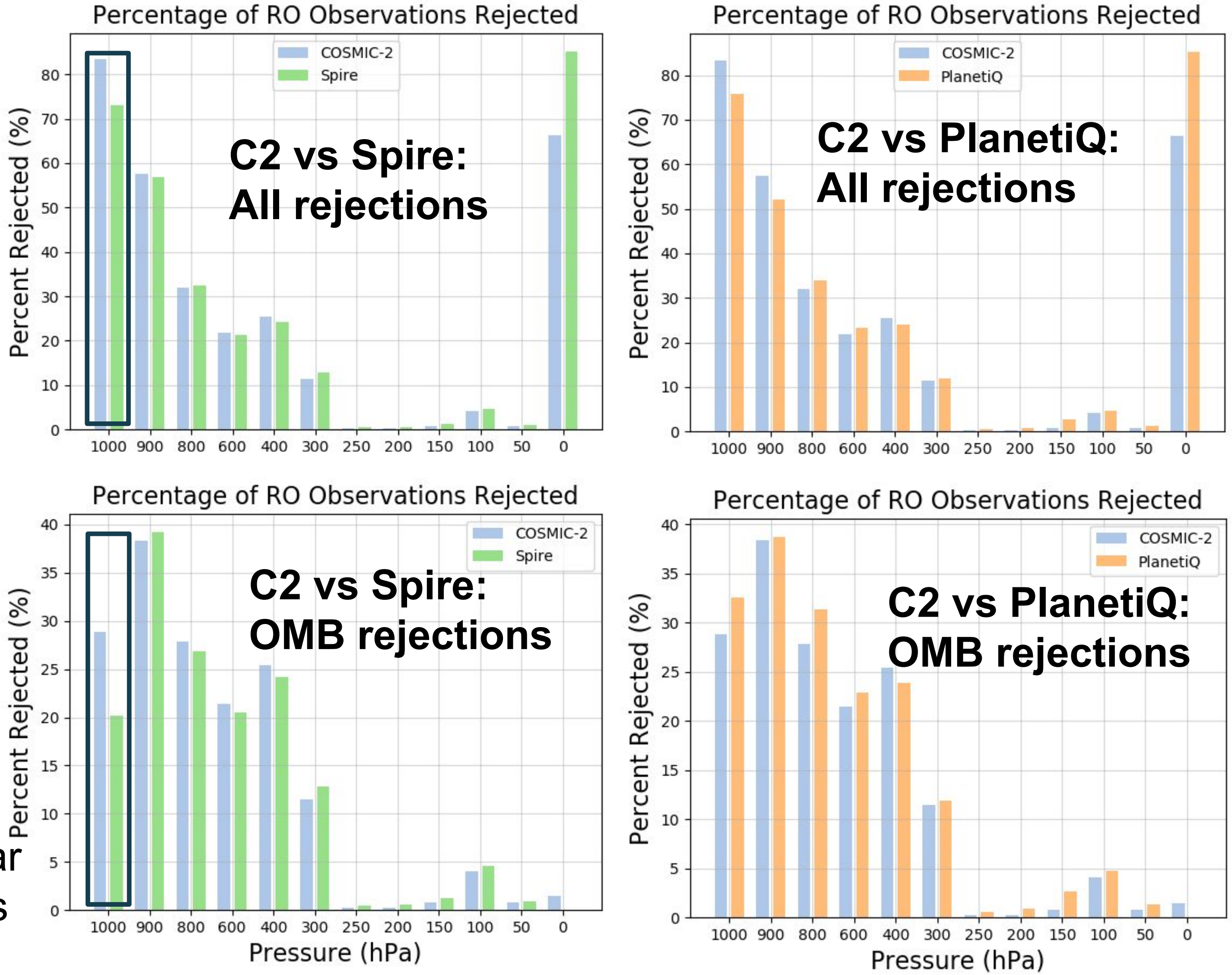


- **Run cycled HAFS forecasts of four 2022 Atlantic hurricanes**: Earl, Fiona, Ian, and Julia
- Each 6-hourly cycled HAFS analysis initializes a 126-h free forecast
- Each experiment generates 132 HAFS analyses from all 4 cases □ use all 132 for DA statistics
- **Use only HAFS forecasts initialized after 24 h of cycled DA for forecast verifications** (86 total)

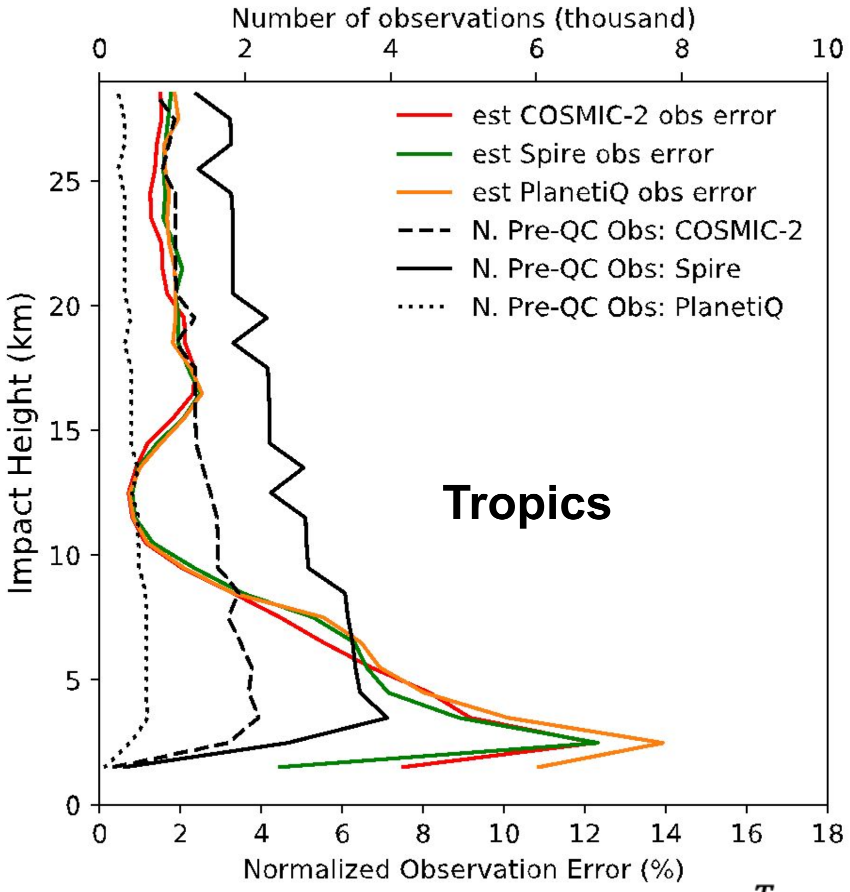
- **CONTROL**: Use all available non-commercial RO data (e.g., COSMIC-2, MetOp, KOMPSAT-5)
- **ROMEX**: Like **CONTROL**, also assimilating EUMETSAT-processed commercial RO bending angles (about 17K Spire and 3K PlanetiQ profiles globally per day)

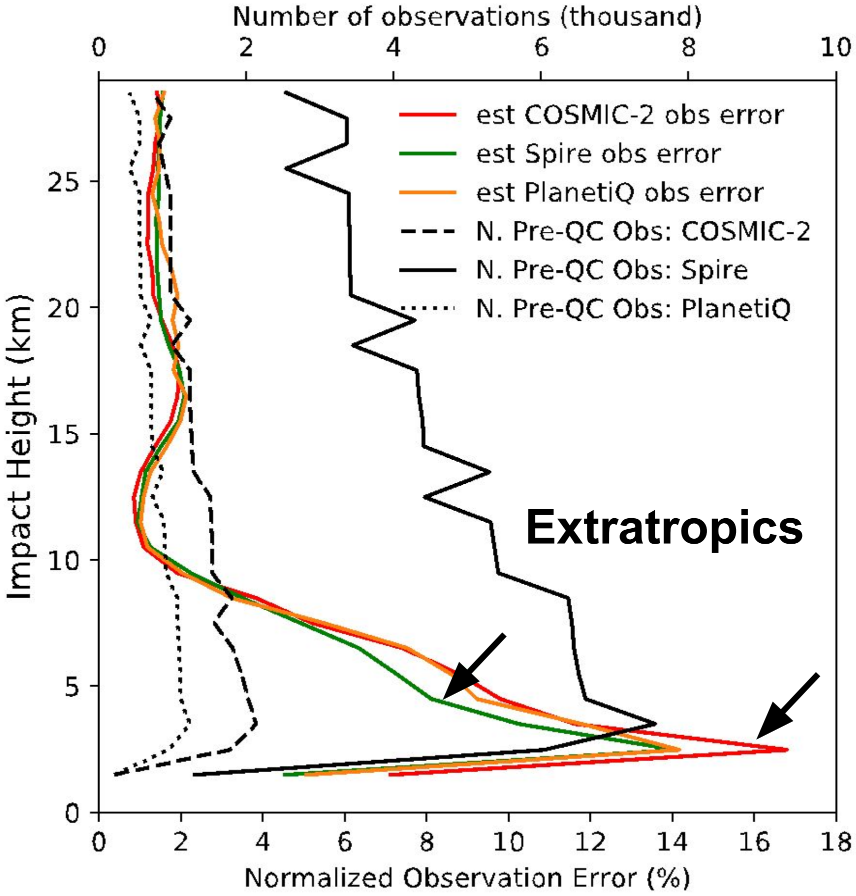
RO Observation Retention in HAFS

- Most HAFS-GSI RO observation rejections in the troposphere result from either:
  - super-refractivity likely conditions in background due to excessively large vertical N gradient
  - (O-B)/O exceeding a latitude, height, and temperature-dependent threshold
- Over 50% of RO obs rejected below 850 hPa, regardless of receiver platform
- PlanetiQ and COSMIC-2 rejection statistics are similar
- Spire and COSMIC-2 rejection statistics are also similar, except near PBL where Spire OMB rejection % is about 10 percentage points lower



Diagnosed Observation Errors





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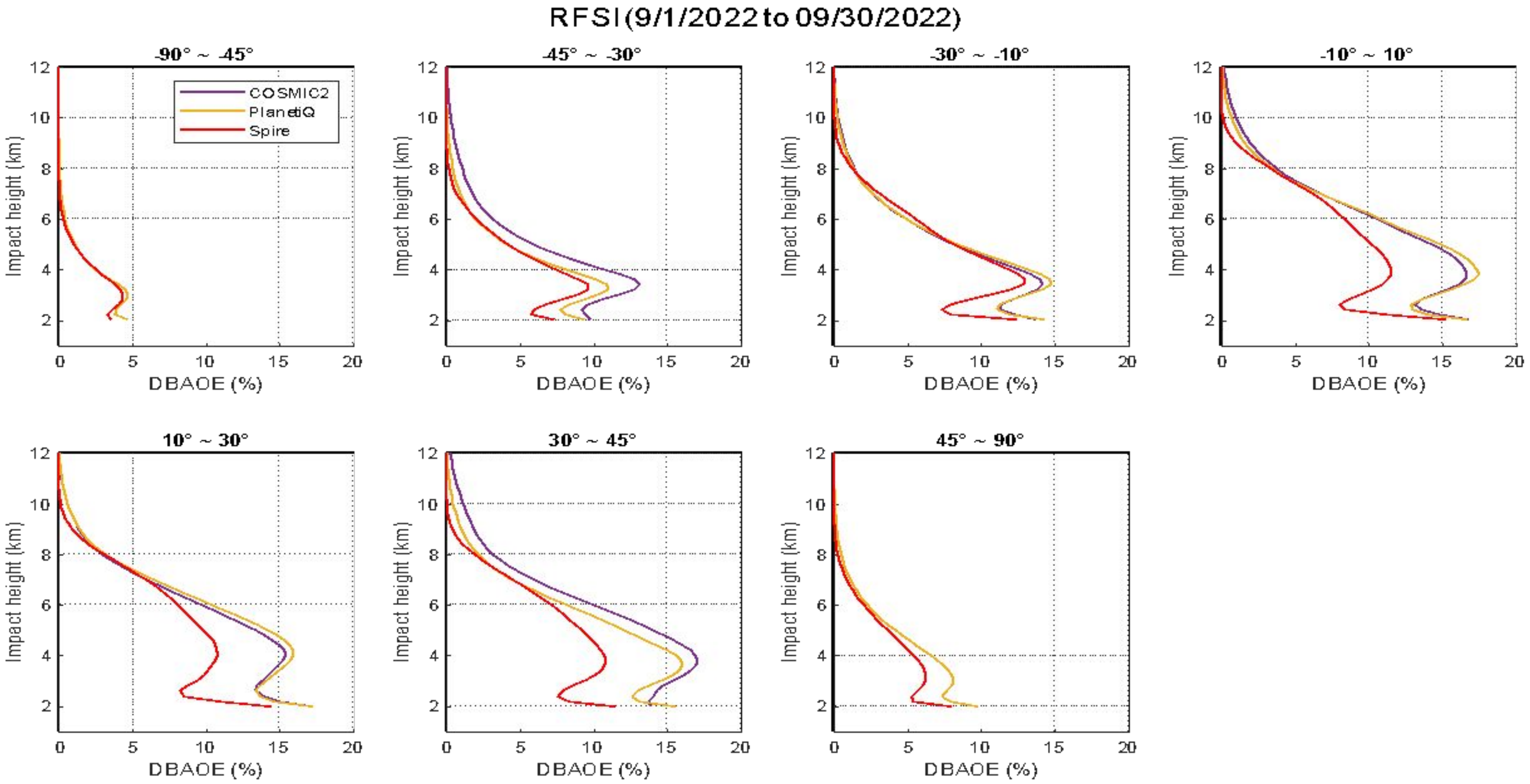
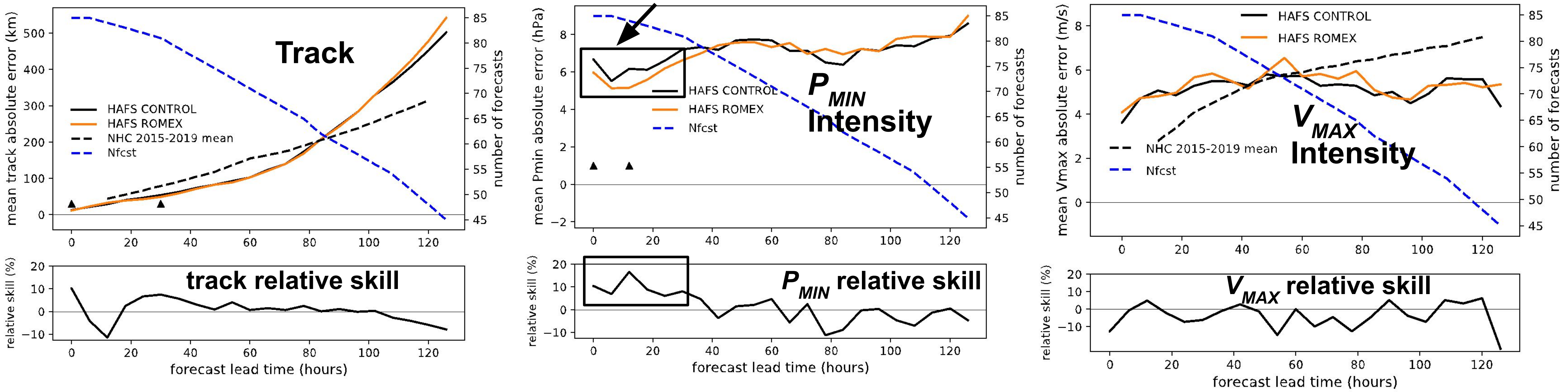
- Use Desroziers et al. (2005): $\widetilde{\sigma_i^o}^2 = \frac{(d_b^o)_i^T (d_a^o)_i}{} = \sum_{j=1}^{p_i} (y_j^o - y_j^b)(y_j^o - y_j^a)/p_i$

Characterizing the Uncertainty of GNSS RO Bending Angles in the Lower Troposphere with the Local Spectral Width Analysis



See poster "Jing et al., Characterizing the Uncertainty of GNSS RO Bending Angles in the Lower Troposphere with the Local Spectral Width Analysis"

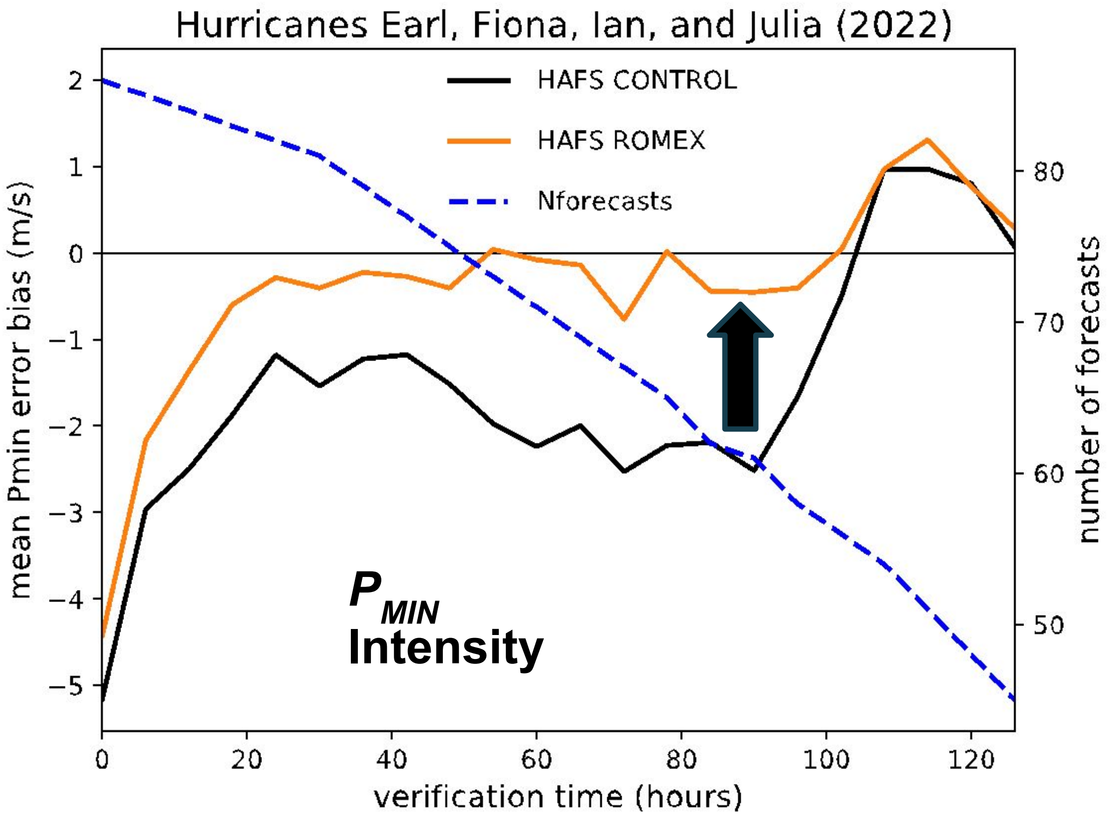
CWD RO DA Impacts on Mean Absolute Forecast Errors

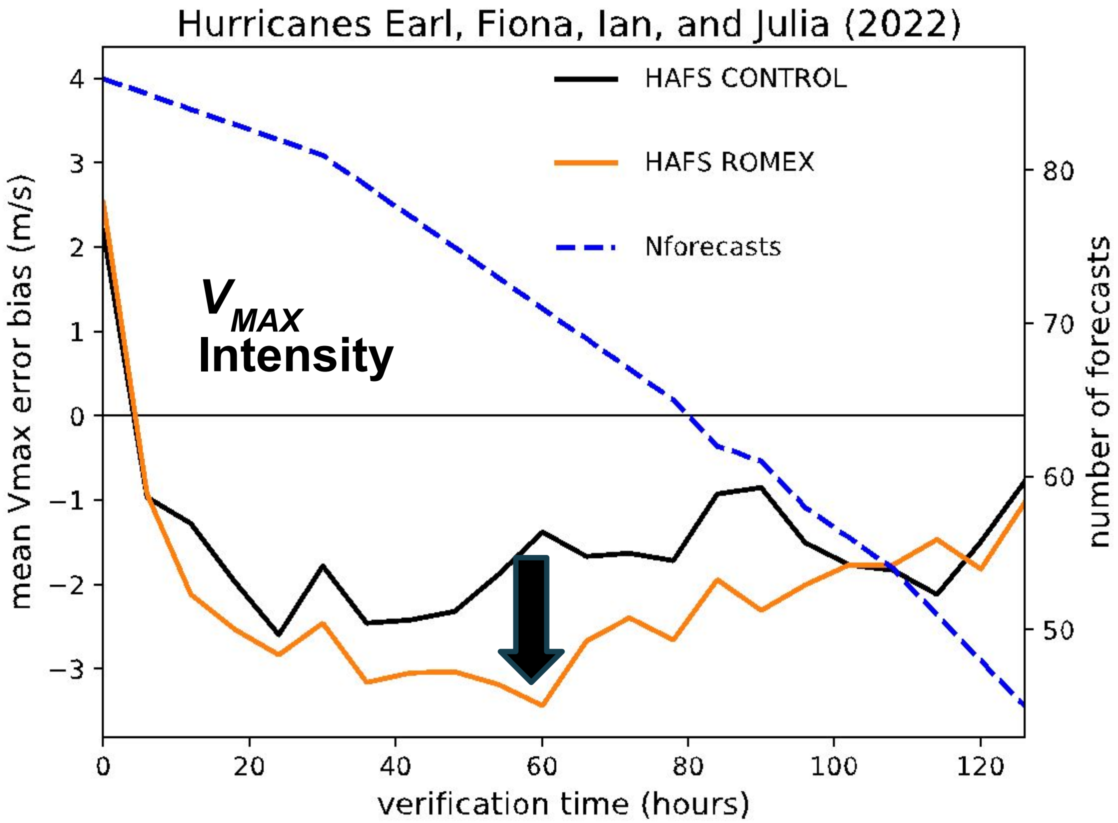


Relative skill = 100 × (err_CONTROL - err_ROMEX) / err_CONTROL → positive values show ROMEX improvement over CONTROL

- **For most forecast verification times, CWD RO impacts on track and intensity absolute forecast errors are neutral** with less then 10% change in ROMEX relative skill versus Control
- **CWD RO improves P_{MIN} forecast relative skill by ~10-15% for short-range forecasts**, statistically significant for t = 0 h and t = 12 h

CWD RO DA Impacts on Forecast Mean Biases

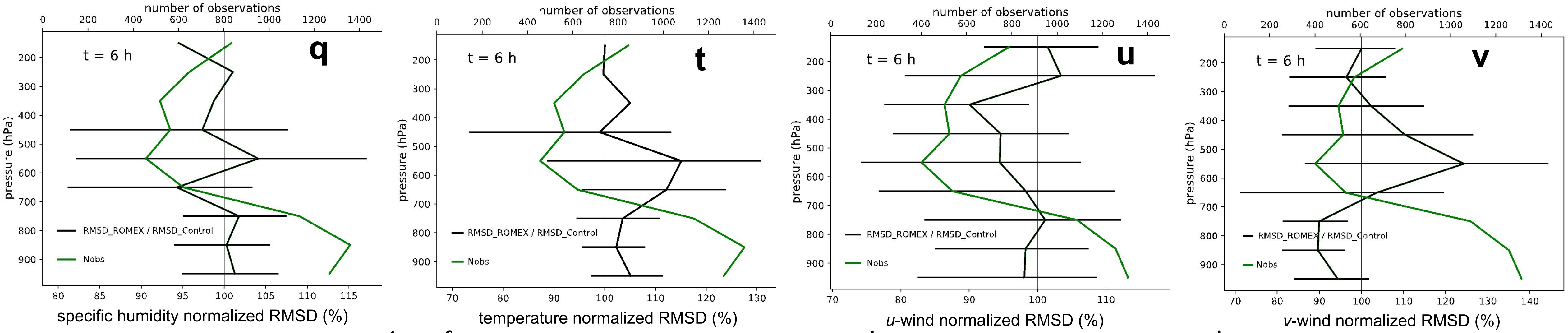




- For much of the forecast period, HAFS Control has an over-intensification bias in P_{MIN} and an under-intensification bias in V_{MAX}
- CWD RO DA nearly eliminates the P_{MIN} forecast over-intensification bias 😀 but it increases the V_{MAX} under-intensification bias 😟

CWD RO DA Impacts on Forecast RMSD versus Dropsondes

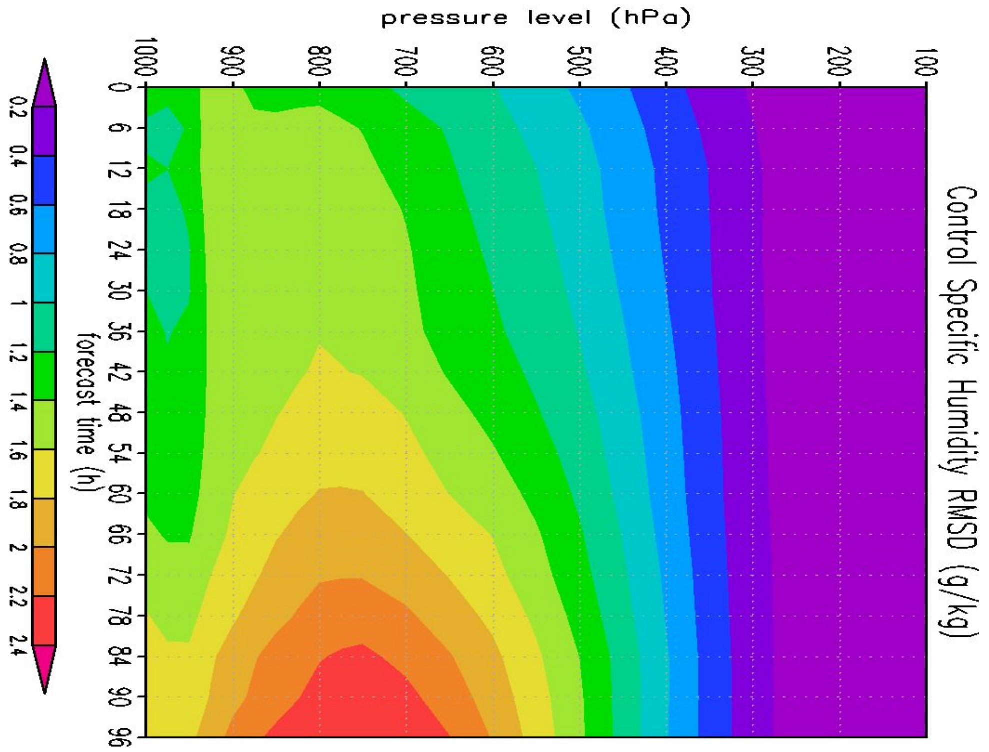
normalized RMSD = 100 × (RMSD_ROMEX / RMSD_CONTROL)

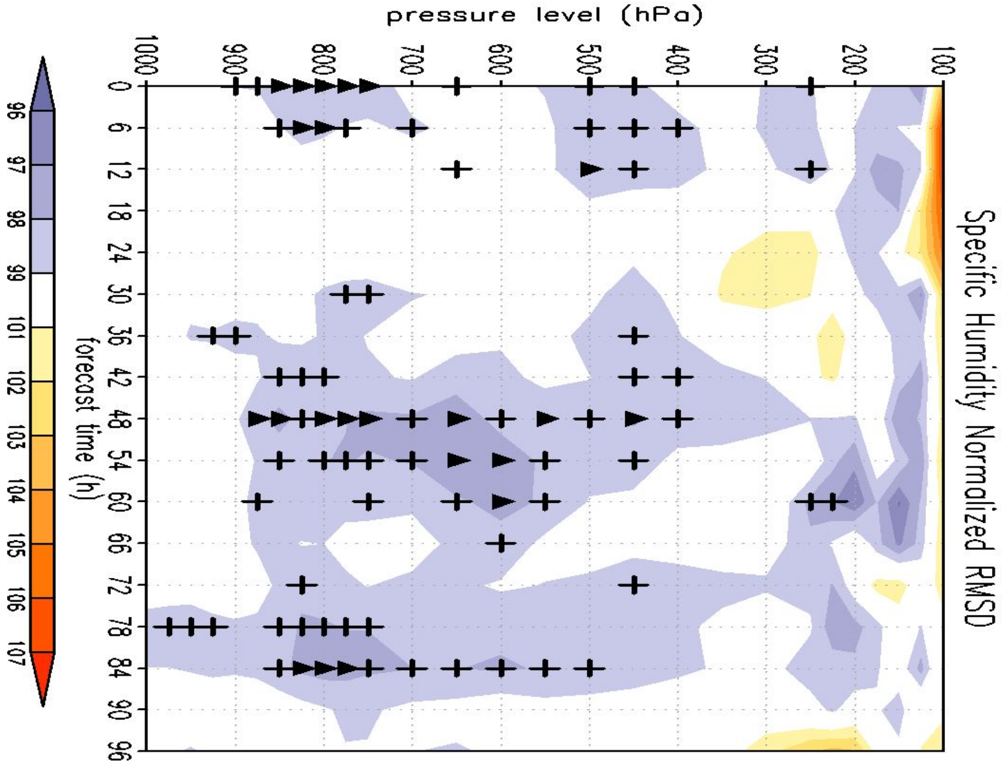


- Use all available TC aircraft reconnaissance mission dropsonde and synoptic radiosonde observations occurring within +/- 1 h of a HAFS 6-h forecast and located within 800 km of the TC center
- NOAA P-3 aircraft missions provide most of the observational data. Therefore, most sonde observations sample only the layer below 700 hPa.
- CWD RO DA has an overall neutral-to-negative impact on short-range HAFS forecast specific humidity and temperature RMSD against dropsondes.
- However, CWD RO DA yields statistically significant improvement in *v*-wind RMSD over the 700-900 hPa layer.

CWD RO DA Impacts on Forecast Specific Humidity RMSD versus ERA5

normalized RMSD = 100 × (RMSD_ROMEX / RMSD_CONTROL)



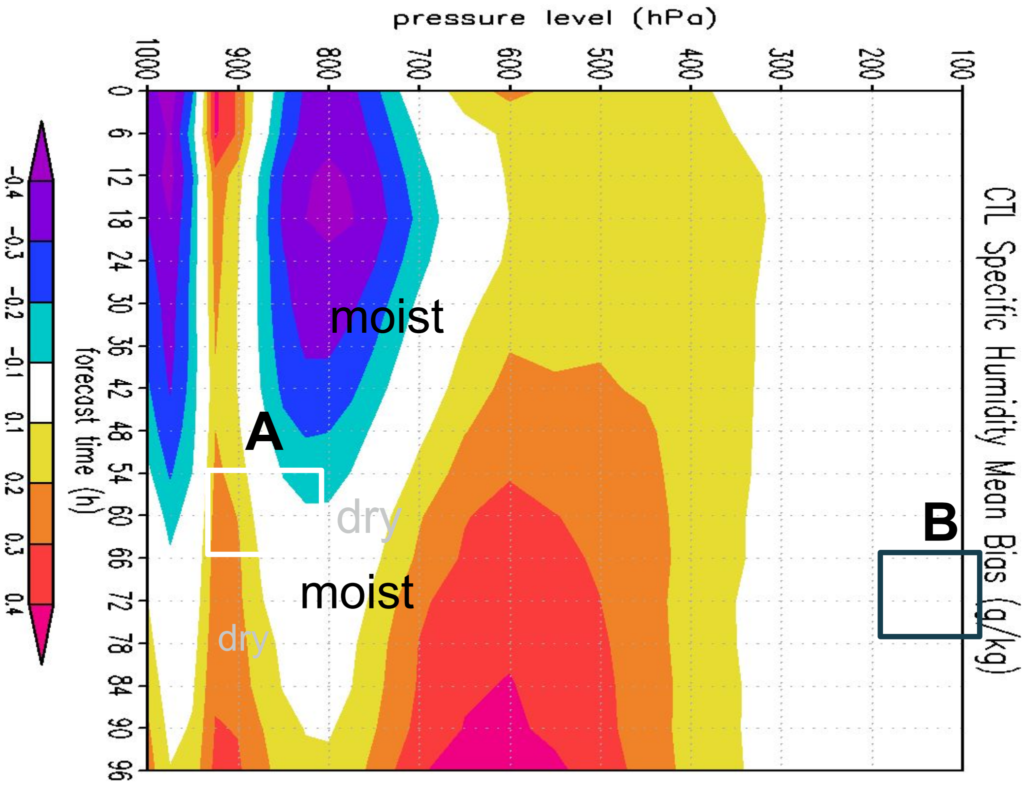


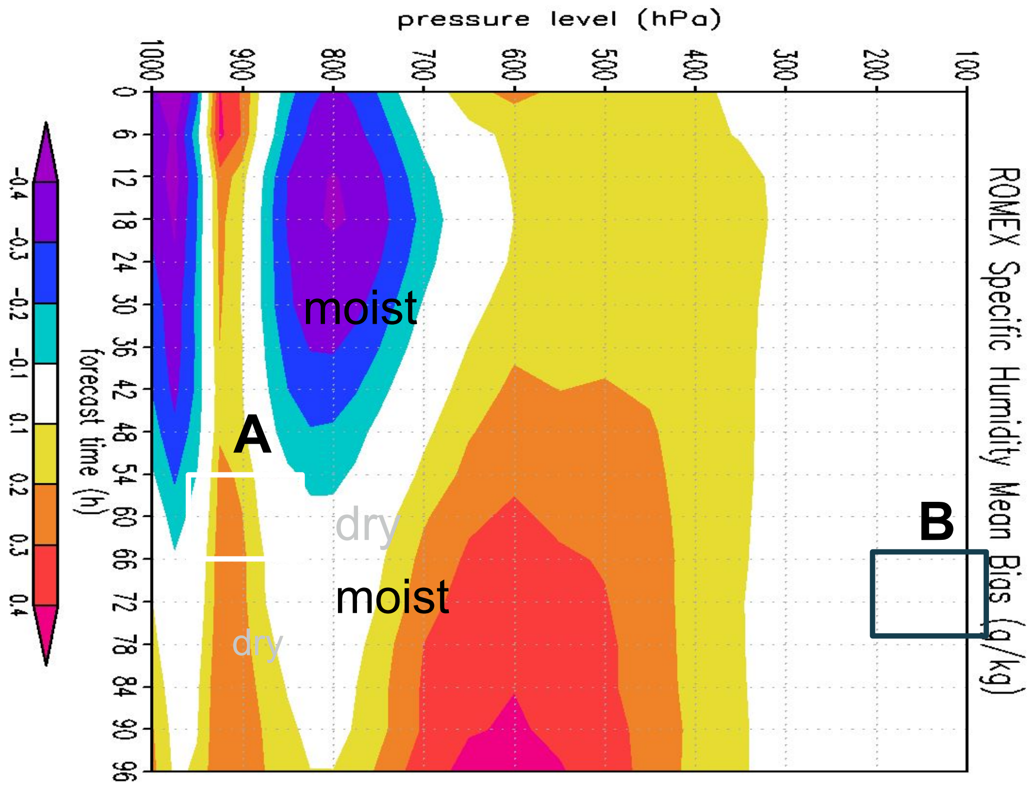
+ : ROMEX improvement statistically significant at the 95% level

▲: ROMEX improvement statistically significant at the 99% level

- **Compared to that of CONTROL, ROMEX specific humidity RMSD against ERA5 analyses is generally reduced by 1-3% over the 900-400 hPa layer**, especially for *t* = 0-6 h and for *t* = 42-84 h forecast periods
- Below 900 hPa, CWD RO DA impacts are generally neutral on HAFS specific humidity RMSD versus ERA5

CWD RO DA Impacts on Forecast Specific Humidity BIAS versus ERA5

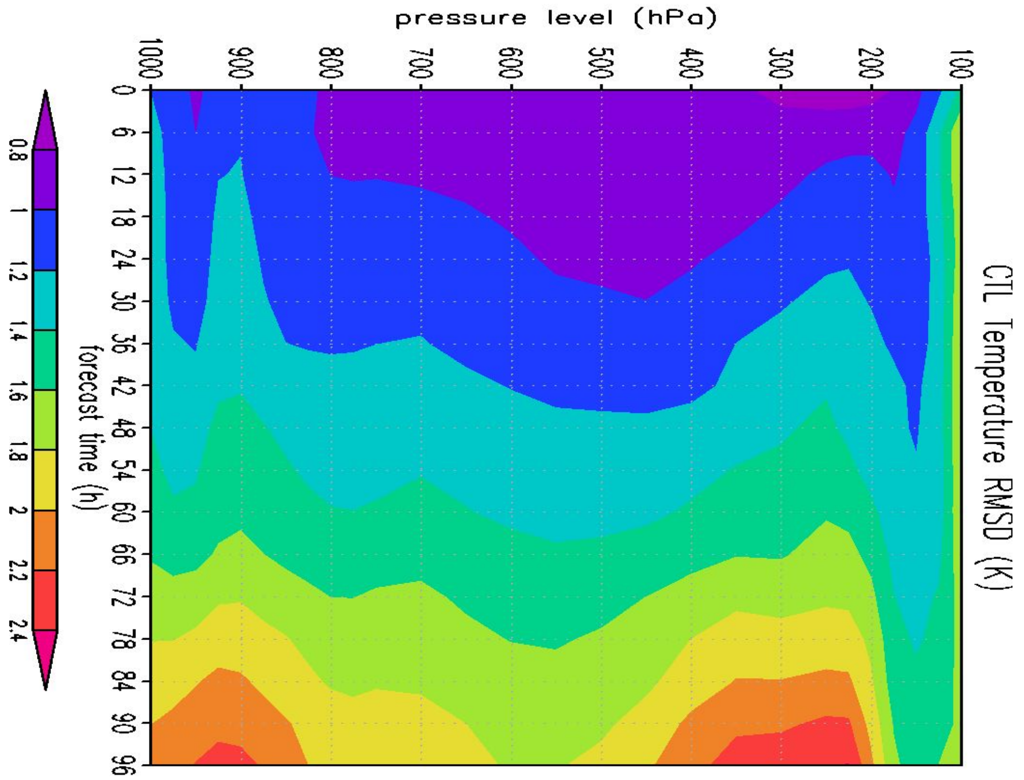


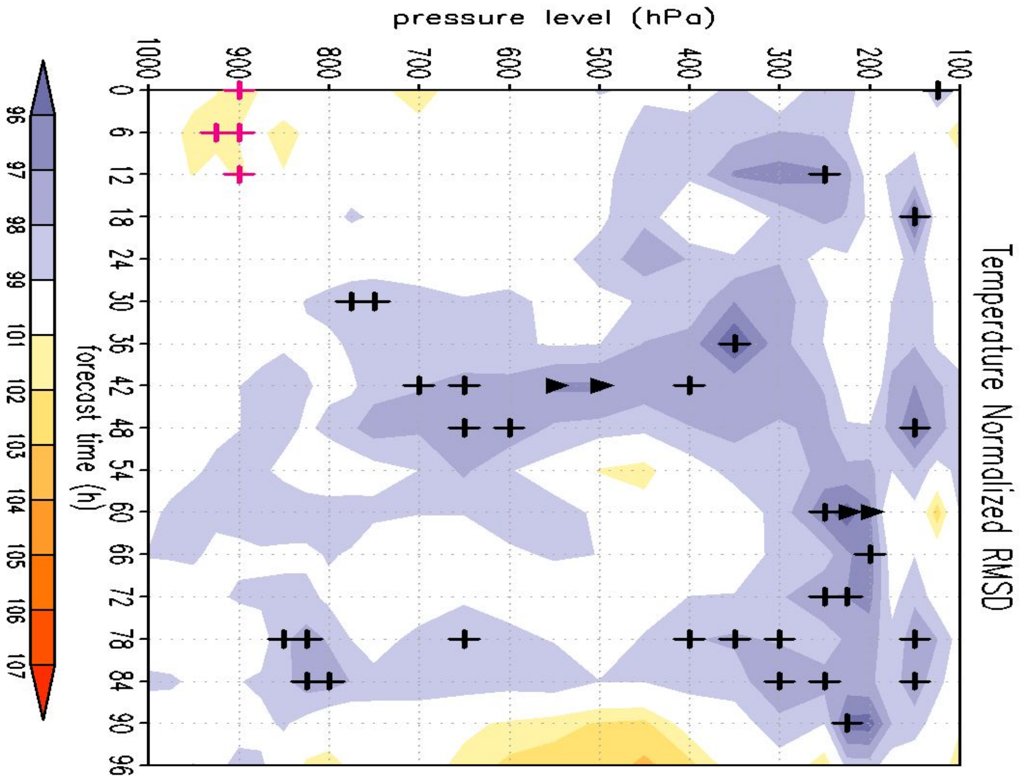


- Throughout much of the forecast period, HAFS CONTROL has a dry bias in the sub-950 hPa and 700-850 hPa layers, and a moist bias around 900 hPa and in the 300-700 hPa layer. Bias is measured against ERA5 analyses.
- **Compared to that of CONTROL, the ROMEX specific humidity bias pattern is similar**, except that the ROMEX dry bias is smaller at 800 hPa, *t* = 12-18 h (“A”) and the ROMEX moist bias is smaller at 900 hPa, *t* > 84 h (“B”).

CWD RO DA Impacts on Forecast Temperature RMSD versus ERA5

normalized RMSD = 100 × (RMSD_ROMEX / RMSD_CONTROL)





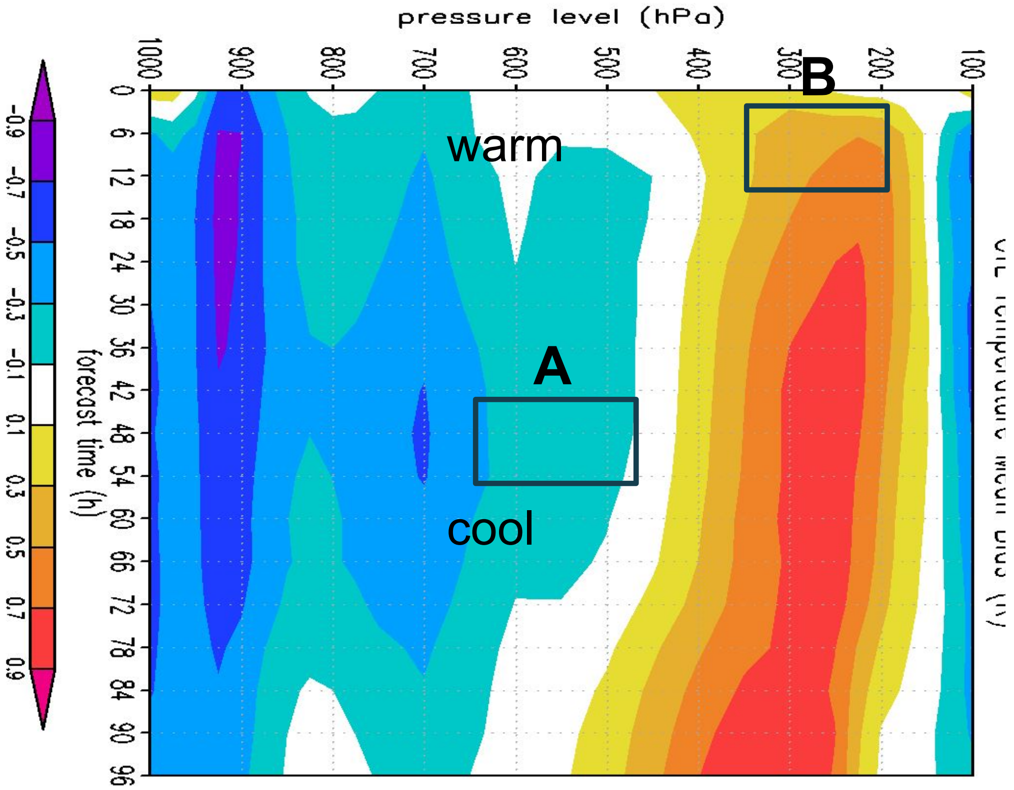
+ : ROMEX improvement statistically significant at the 95% level

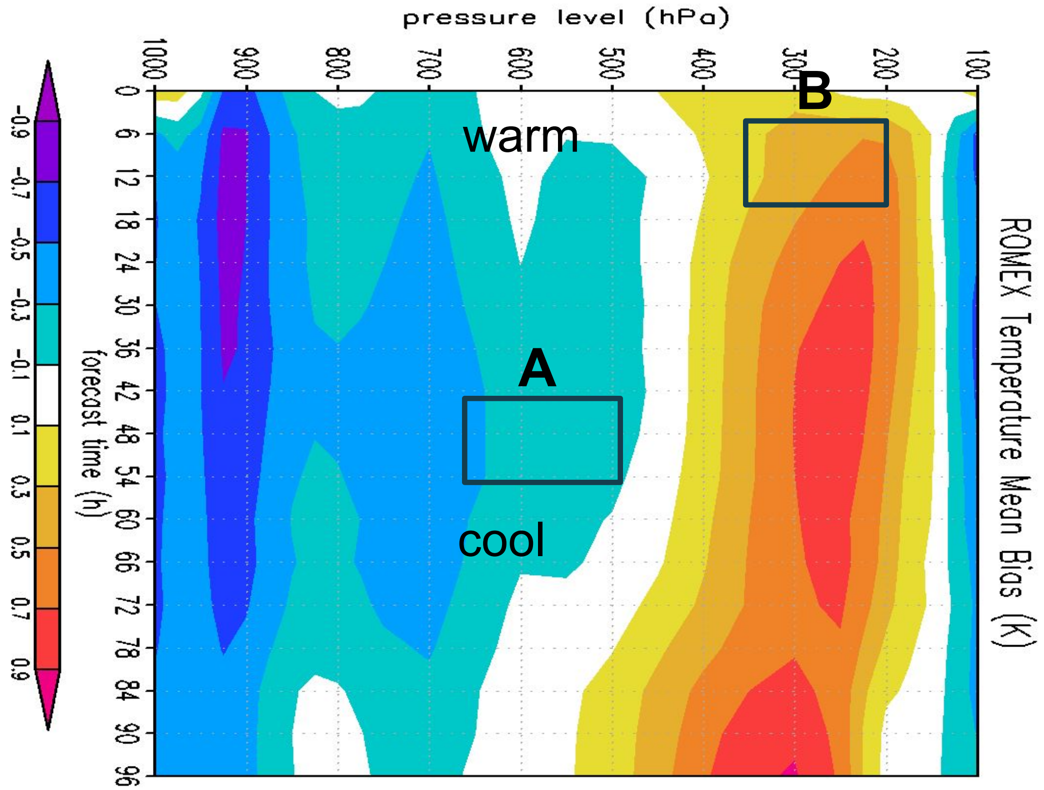
+ : ROMEX degradation statistically significant at the 95% level

▲: ROMEX improvement statistically significant at the 99% level

- **Compared to that of CONTROL, ROMEX temperature RMSD against ERA5 analyses is generally reduced by 1-4% over the 400-200 hPa upper troposphere layer for most forecast times.**
- We also find pattern of **improved ROMEX temperature RMSD in the 900-500 hPa layer for medium-range forecasts.**
- ROMEX 900 hPa temperature RMSD is degraded (95% sig level) versus CONTROL for *t* = 0-12 h forecasts.

CWD RO DA Impacts on Forecast Temperature BIAS versus ERA5

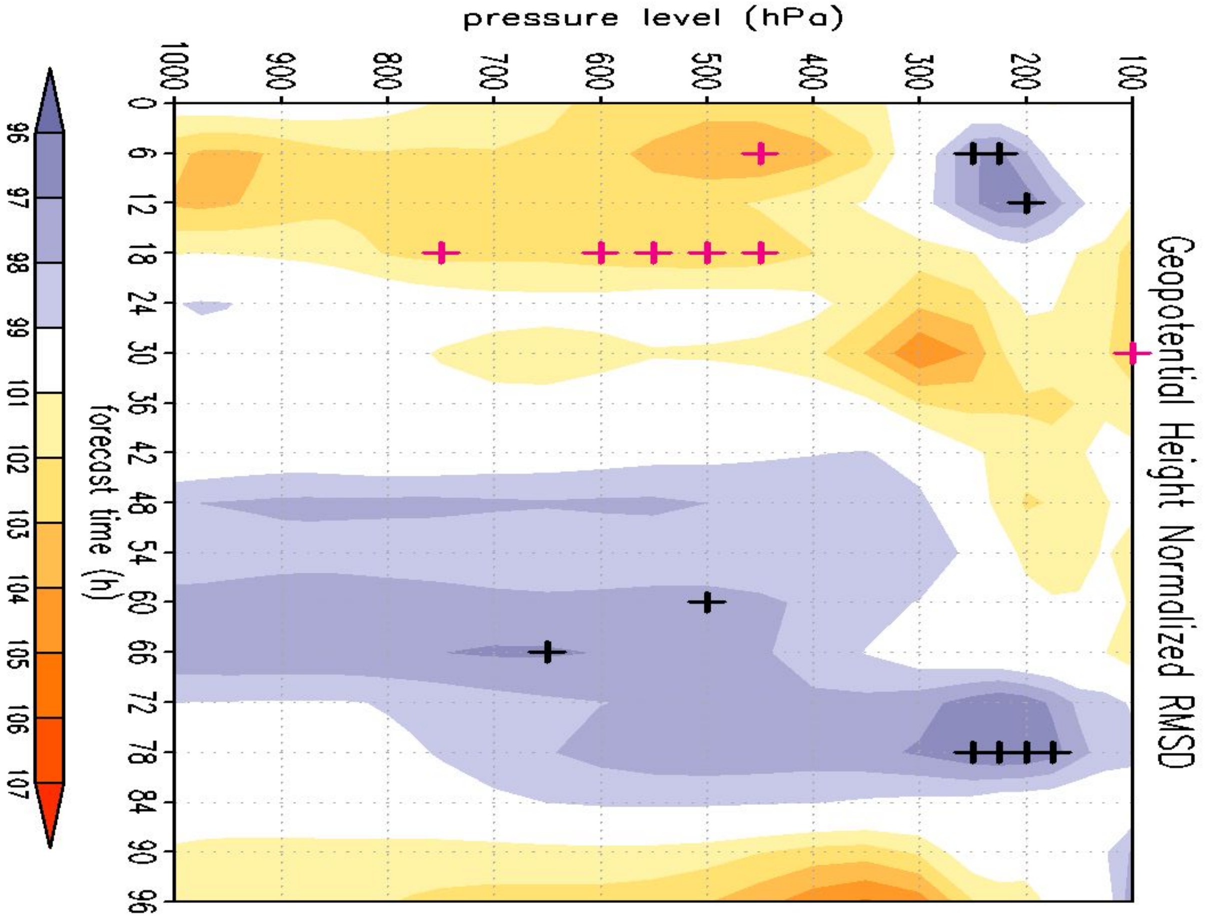


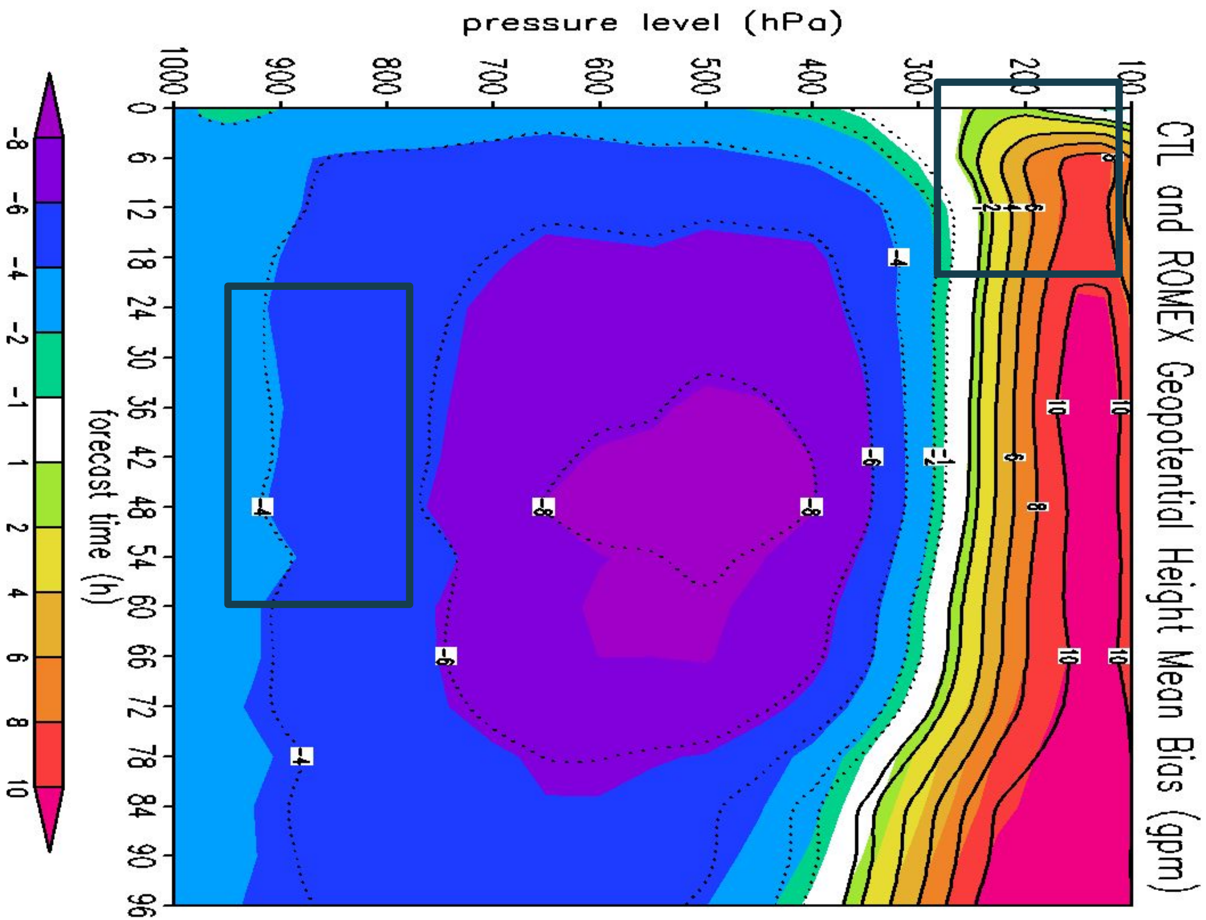


- Throughout much of the forecast period, HAFS CONTROL has a cool bias below 500 hPa and a warm bias in the 450-150 hPa layer. Bias is measured against ERA5 analyses.
- **Compared to that of CONTROL, the ROMEX specific humidity bias pattern is similar**, except that the ROMEX cool bias is smaller at 700 hPa, *t* = 42-54 h (“A”) and the ROMEX warm bias is smaller around 250 hPa, *t* = 78 h (“B”).

CWD RO DA Impacts on Forecast Geopotential Height versus ERA5

Control: shaded **ROMEX: contoured**





- ROMEX has a larger geopotential height RMSD and negative height bias below 300 hPa through *t* = 24 h, vs. Control
- These trends reverse for later forecast periods, although note increased ROMEX + height bias in UT around *t* = 84 h

Summary and Conclusions

- We have evaluated impacts of assimilating the ROMEX Spire and PlanetiQ RO bending angle observations in ~90 HAFS forecasts, using four 2022 Atlantic hurricanes
- Spire and PlanetiQ observation errors diagnosed from the ROMEX experiment are ~2-3% smaller compared to those of COSMIC-2 in the extratropical lower troposphere
- **Assimilated PlanetiQ and Spire data improve HAFS TC forecast error statistics by some metrics**, which include:
  - ~10-15% improvement in P_{MIN} forecast intensity error relative skill for short-range forecasts
  - Near-elimination of a ~ 1-3% P_{MIN} over-intensification bias throughout forecast period
  - Reduced HAFS specific humidity and temperature RMSD against ERA5 for medium-range forecasts above 900 hPa
- However, assimilated PlanetiQ and Spire data have neutral-to-negative impacts by other evaluation metrics, which include:
  - track errors (mostly neutral)
  - V_{MAX} intensity errors (mostly neutral)
  - short-range forecast q and t RMSD versus dropsondes (neutral to negative)
  - Increased short-range forecast geopotential height RMSD and negative bias

Questions?

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