Global NWP Impacts of Infrared Sounders from Geostationary Orbit

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Motivation

The goal of numerical weather prediction (NWP) is to enable better decision-making. This requires a good forecast initialization, which benefits from good observations combined with a numerical model through data assimilation. Low Earth Orbit (LEO) hyperspectral IR radiances provide high vertical resolution observations but suffer from limited horizontal and temporal resolution. The Geostationary eXtended Observations Sounder (GXS) is designed to reduce these limitations by providing higher spatiotemporal observations, allowing views between clouds, more homogeneity in cloudy scenes, and the ability to observe rapidly evolving phenomena with lower data latency. This provides new information content for NWP, including wind information from the higher temporal resolution.

Spatial coverage of IR Sounders

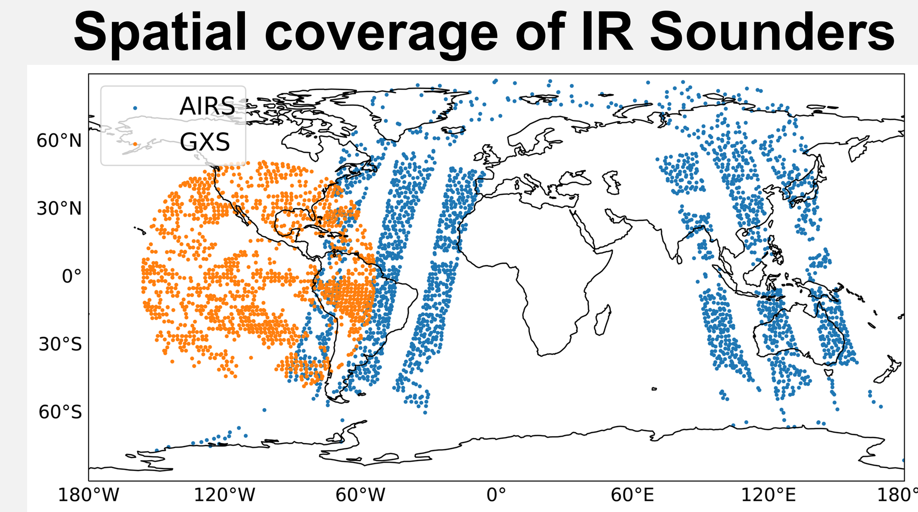

Figure 1: Spatial coverage of assimilated GEO (GXS) vs LEO (AIRS) hyperspectral IR sounders at ~500hPa. Notice orbital gaps of LEO sounder observation over targeted region, in this case CONUS, that are filled in by GXS.

Observing System Simulation Experiments (OSSE)

A tool to assess sensitivities and capabilities of proposed observing systems. Includes

1) the GMAO Nature Run (7km, 30min temporal resolution),
2) the Goddard Earth Observing System (GEOS) atmospheric data assimilation system (DAS), assimilating data in hourly bins, and
3) Global observations simulated from the NR with realistic errors added to statistically resemble operational system.

Updated experiments from McGrath-Spangler et al. (2022) using 2020 observing system, updated DAS, and extended to September to capture tropical cyclones in the Nature Run.

Geostationary IR Observations

In addition to a baseline of the operationally assimilated observing system in the control, 4 identical geostationary IR sounders were assimilated at the locations of GXS, MTG, GIIRS, and Himawari. MTG-S was used as the baseline instrument with a spectral range of 650 – 2500 cm^{-1} yielding 4km spatial resolution and an hourly "full-disk" scan.

Geostationary IR Sounders

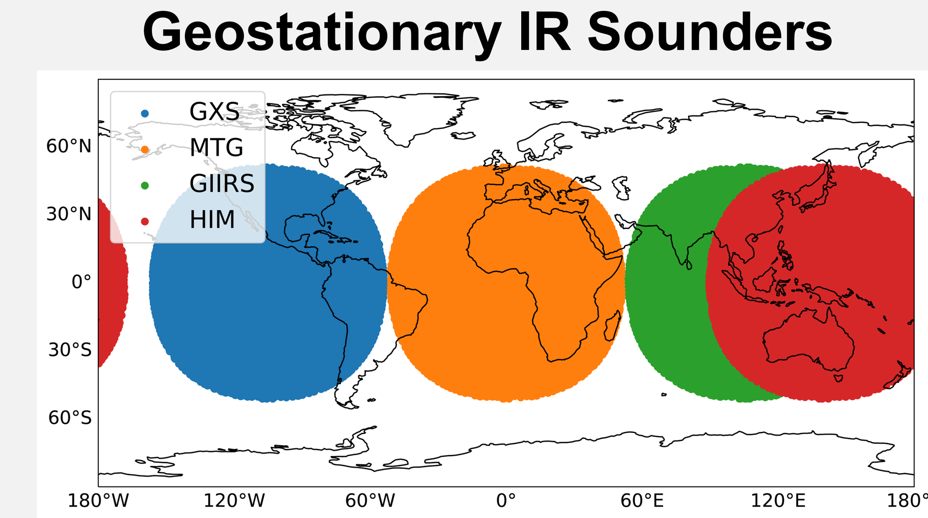

Figure 2: Locations of hourly GEO IR sounder observations that were assimilated in the experiment, in addition to the baseline observing system.

Results

Assimilation of geostationary hyperspectral IR sounders reduces root mean square error of key atmospheric variables in the analysis, primarily in the tropics. Improvements in the wind estimates are partially due to the observations directly, but also due to the complex interactions within the DAS and high temporal observations of water vapor and temperature that provide information on the wind through their advection, meaning that geostationary IR sounders can provide novel information to the system. This results in improved initial conditions for the forecasts that translate to statistically significant improvements on the scale of several days. Over CONUS, the forecast sensitivity observation impact (FSOI) metric, calculated over the 4 synoptic times, shows that GXS has the largest impact on the 24 h forecast error. In addition to large-scale improvements, GXS can provide information necessary to reduce hurricane track errors.

Specific Humidity

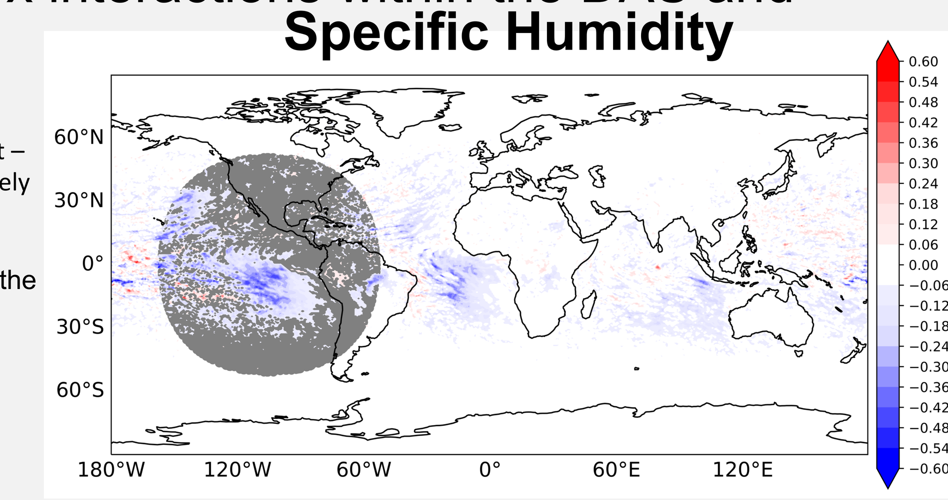

Figure 4: Specific humidity root mean square analysis error difference (experiment – control) at approximately 850 hPa. Blue colors indicate an improvement due to the assimilation of geostationary IR sounders. The gray circle indicates the region observed by GXS.

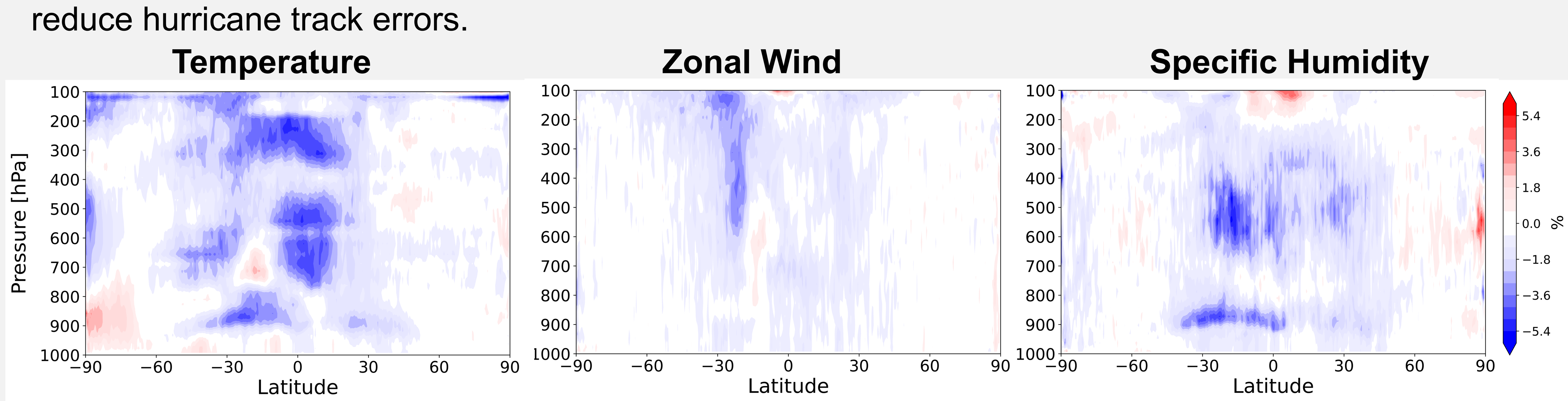

Figure 3: Normalized zonally averaged root mean square analysis error difference (experiment-control)/control for (left) temperature, (middle) zonal wind, and (right) specific humidity. Blue colors indicate an improvement due to the assimilation of geostationary IR sounders.

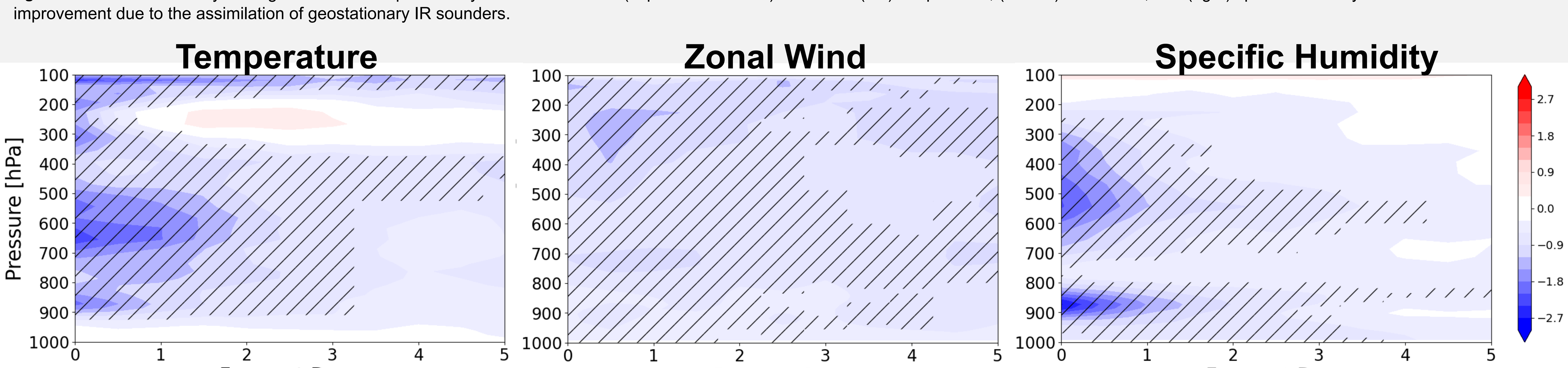

Figure 3: Normalized globally averaged root mean square forecast error difference (experiment-control)/control for (left) temperature, (middle) zonal wind, and (right) specific humidity. Blue colors indicate an improvement due to the assimilation of geostationary IR sounders.

CONUS FSOI

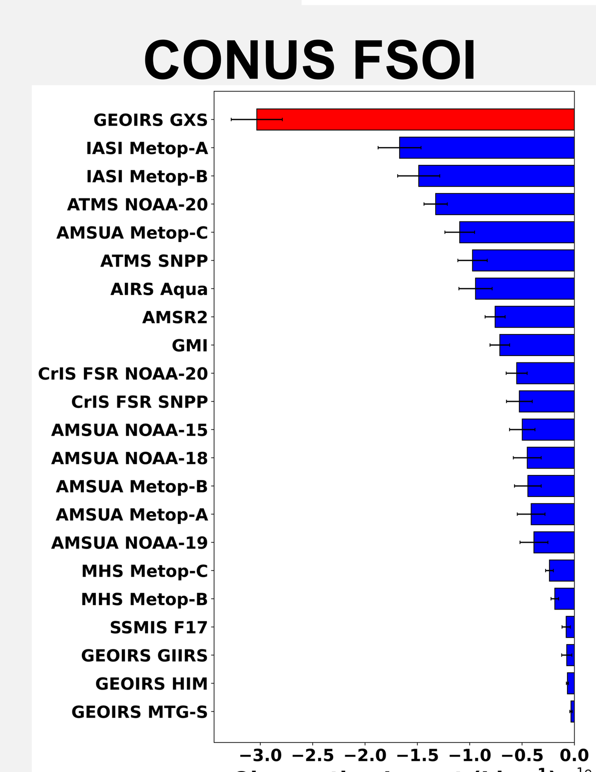

Figure 5: Regional FSOI from satellites calculated over the CONUS region from the 00, 06, 12, and 18 UTC analysis cycles. GXS is highlighted in red.

Forecast Track Error

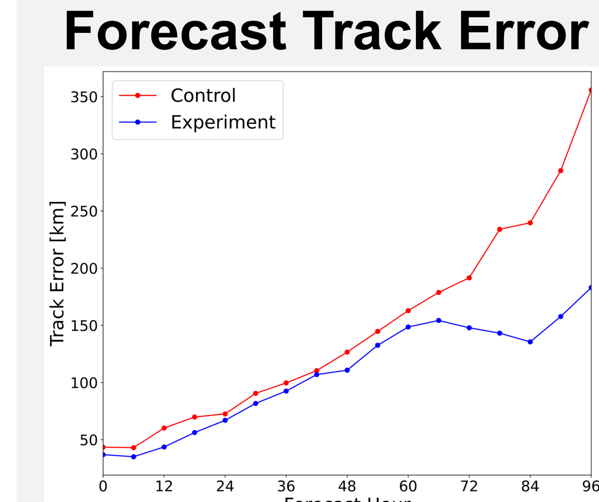

Figure 6: Forecast track error for a Gulf of Mexico hurricane represented in the Nature Run. The estimates are averaged over 16 forecasts initialized every 6 hours that then run for 5 days. Track error is computed for the portion of each forecast that corresponds to a time the hurricane exists in the Nature Run.

TPW

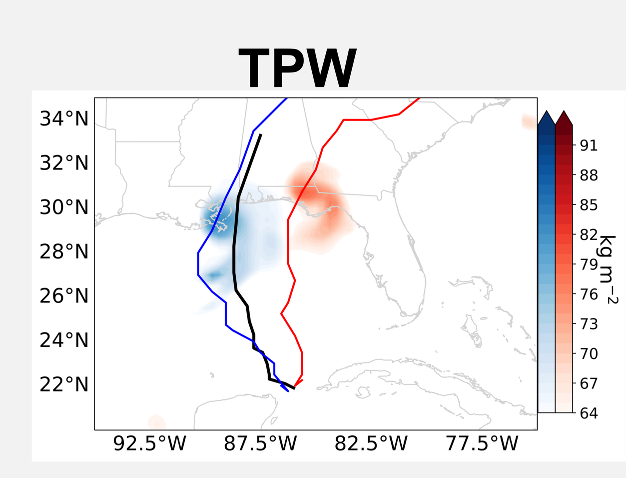

Figure 7: 72 h forecasted total precipitable water for the hurricane in Figure 6 from the (red) control and (blue) experiment. The black line indicates the track represented in the Nature Run whereas the red and blue lines indicate the forecasted tracks. At landfall, the control track error is over 2x greater than in the experiment assimilating geostationary IR sounders.

Summary

Assimilation of geostationary IR sounders can improve global NWP analysis and forecast estimates of large-scale weather variables. The novel, high spatiotemporal observations inform initialization of hurricane forecasts and may lead to improvements in their estimation. Over CONUS, GXS has the largest impact on 24-h forecast error. These advancements have a role to play in enabling better decision-making.

Acknowledgments and References

The authors thank NASA's NCCS program and Ron Errico for developing the baseline OSSE system. Funding was provided by the NOAA and NASA GeoXO program.

McGrath-Spangler, E. L., McCarty, W., Privé, N. C., Moradi, I., Karpowicz, B. M., & McCorkel, J. (2022). Using OSSEs to Evaluate the Impacts of Geostationary Infrared Sounders, *Journal of Atmospheric and Oceanic Technology*, *39*(12), 1903-1918. doi: 10.1175/JTECH-D-22-0033.1

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