Complementary roles of LEO and GEO IR Sounders in NWP Evaluated using an OSSE Framework

Erica McGrath-Spangler[1,2], Nikki Privé[1,2], Bryan Karpowicz[1,3], Min-Jeong Kim[1], Andrew Heidinger[4]

[1]NASA GSFC GMAO; [2]Morgan State University; [3]University of Maryland Baltimore County; [4]GeoXO Program Office, NOAA/NESDIS

National Aeronautics and Space Administration

Key findings

LEO and GEO sounders complement one another, providing key information on different spatiotemporal scales necessary for the best representation of atmospheric phenomena that span multiple scales. A LEO platform provides high-latitude observations and global context to improve global NWP. A GEO platform provides temporal consistency in targeted regions, which provides critical information when other observations are lacking.

Motivation

NOAA and NASA are in the process of developing the United States' next generation of satellite missions, including the Near Earth Orbit Network (NEON) and the Geostationary eXtended Observations (GeoXO) programs. As part of this planning, questions have arisen about the unique and complementary roles of LEO and GEO platforms in numerical weather predictio (NWP).

NASA's Global Modeling and Assimilation Office (GMAO) Observing System Simulation Experiment (OSSE) framework was used in the evaluation of hyperspectral infrared (IR) sounder observations from both platforms to evaluate their distinct roles in NWP.

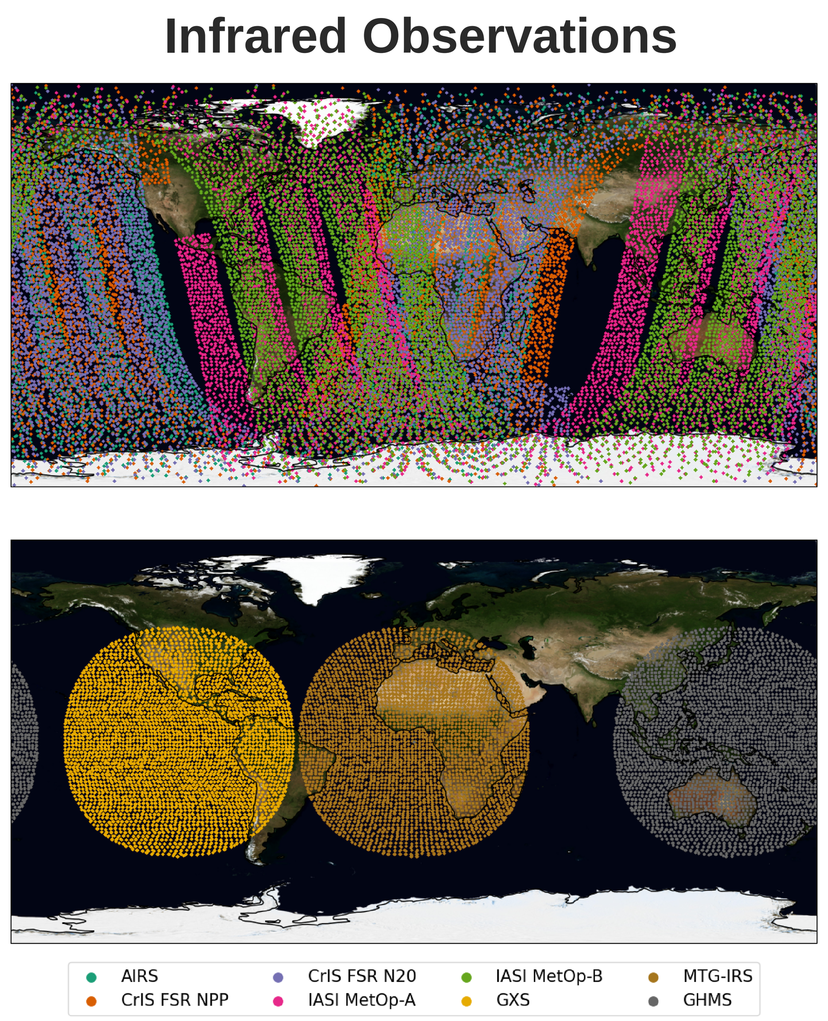

Figure 1: All hyperspectral infrared radiances assimilated in the OSSE for a 6 h period centered on OSSE time 0000 UTC 1 Aug before quality control for (top) LEO orbits and (bottom) GEO orbits.

Observing System Simulation Experiments (OSSE)

Using the GMAO OSSE framework, we ran three experiments:

1. LEO+GEO: 2020 Observing System + global ring
2. LEO Only: 2020 Observing System
3. GEO Only: 2020 Observing System + global ring – LEO IR sounders

Similar setup to McGrath-Spangler et al. (2024), the OSSE is used to assess the sensitivities and capabilities of proposed observing system and future orbital configurations.

NWP Results

Analysis impacts show that denying either LEO or GEO sounders results in a degradation in the RMS error. Loss of GEO sounders has largest impact in the tropics, but losing the LEO sounders results in a degraded forecast that extends to the high latitudes where those are the only IR observations available.

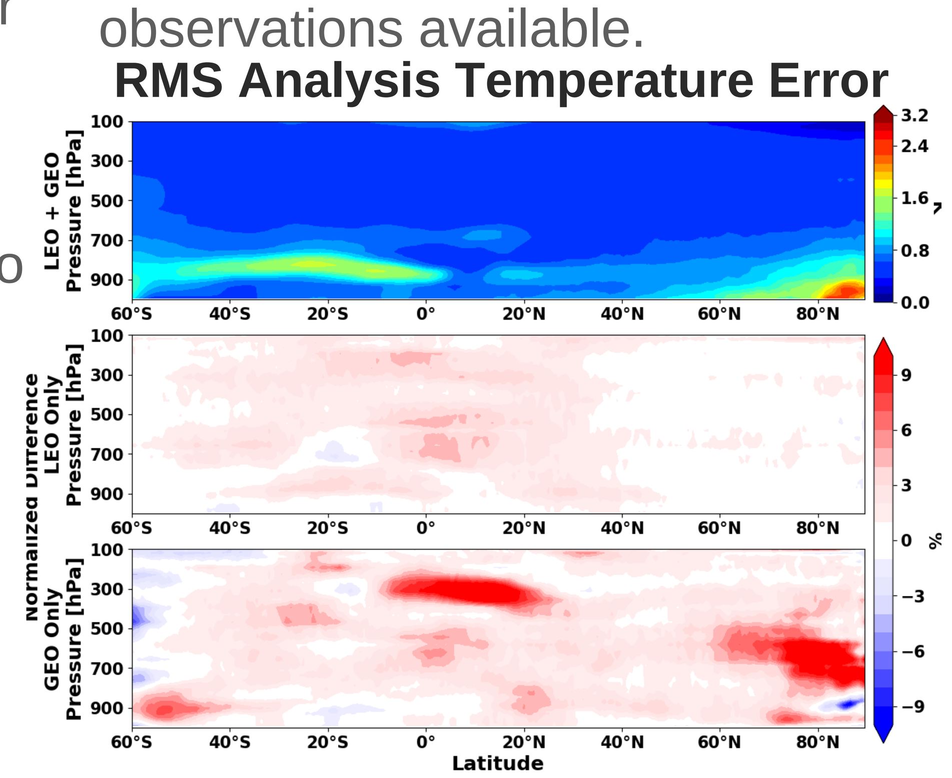

Figure 2: (top) Temperature (K) zonal root mean square error in the LEO + GEO experiment for the (left) global and (right) GXS domain. (middle) The normalized change in RMSE (%) relative to the LEO + GEO experiment by withdrawing the GEO IR sounders. (bottom) The normalized change in RMSE (%) relative to the LEO + GEO experiment by withdrawing the LEO IR sounders. Blue or red indicates an improvement or degradation, respectively.

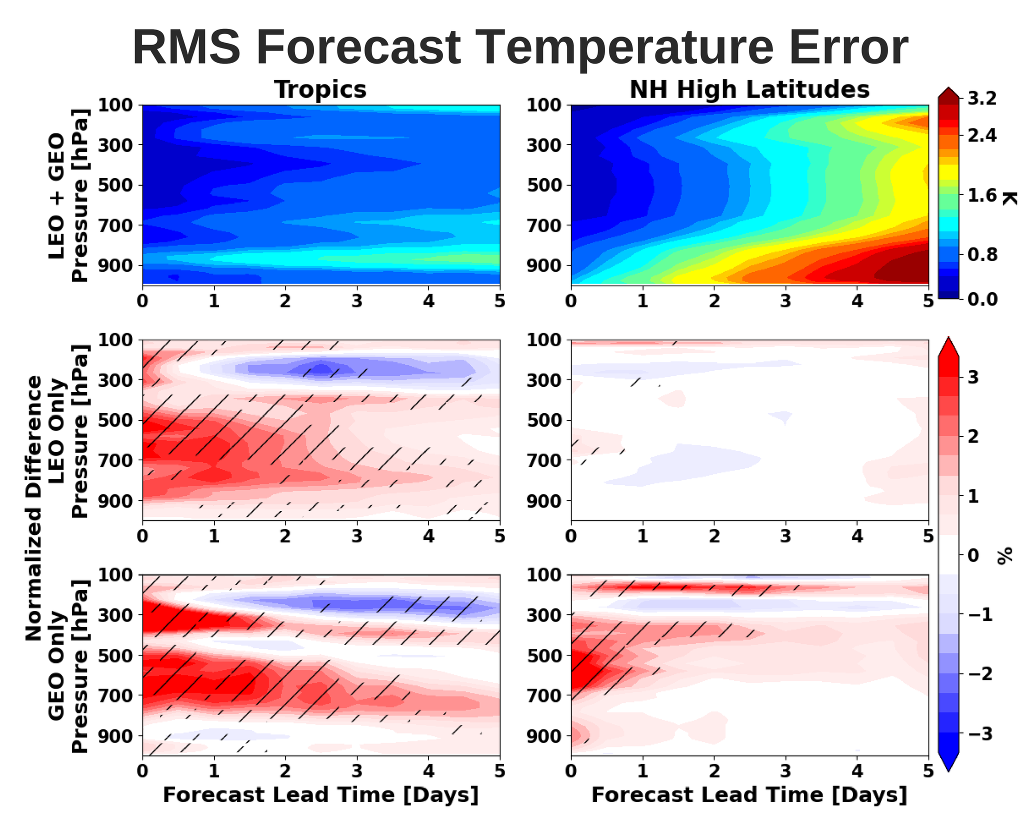

Figure 3: (top) Domain average root mean square error for temperature (K) as a function of pressure and forecast time in the LEO + GEO experiment for the (left) global and (right) tropical domains. (middle) The normalized change in RMSE (%) relative to the LEO + GEO experiment by withdrawing the GEO IR sounders. (bottom) The normalized change in RMSE (%) relative to the LEO + GEO experiment by withdrawing the LEO IR sounders. Calculations are done for the 0000 UTC forecasts only. Blue or red indicates an improvement or degradation, respectively. Taking into account autocorrelation, hatching indicates significance at the 90% level.

The analyses are used in the initialization of forecasts, so a degraded analysis contributes to a degraded forecast. Loss of either sounder platform produces a statistically significant degraded forecast in the tropics, but the Arctic forecast experiences the greatest degradation from the loss of the LEO sounders.

Forecast Sensitivity Observation Impact (FSOI)

FSOI is calculated as a measure of the 24 h moist energy error norm reduction, typically shown as a bar graph, and measures how much an instrument reduces the forecast error. Evaluated over CONUS, previous work has shown that the GeoXO sounder performs most of the work of satellite radiances at reducing error (McGrath-Spangler et al., 2024). Examining the spatial distribution, a GEO platform provides more consistent observation count for a given location across analysis cycles and therefore a more temporally consistent beneficial impact.

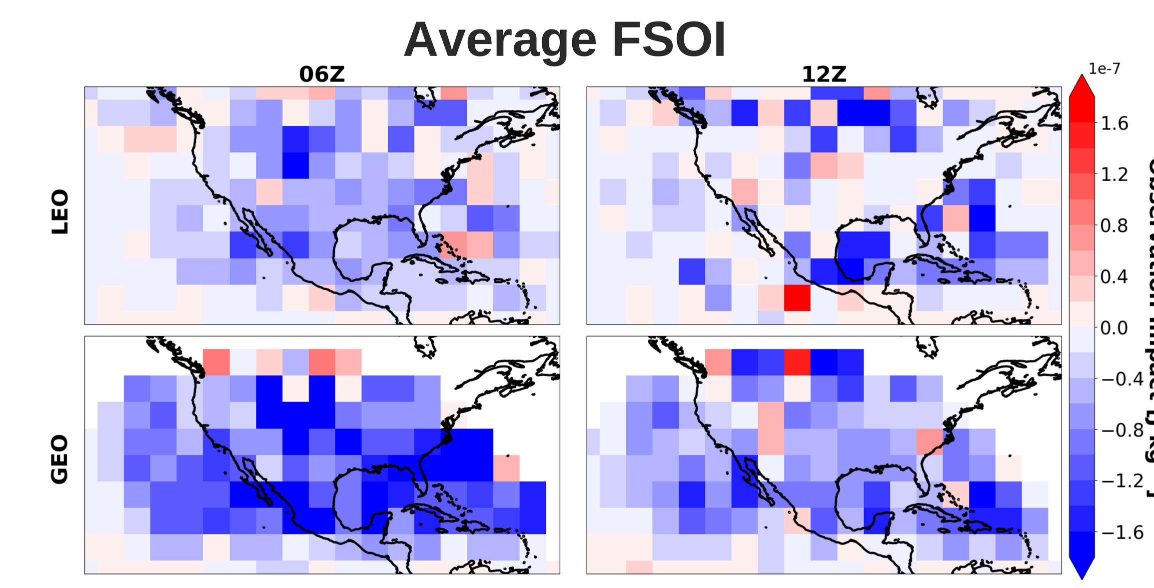

Figure 4: Average FSOI per analysis cycle calculated over CONUS for the (left) 0600 UTC and (right) 1200 UTC analyses. Average FSOI compare (top) LEO and (bottom) GEO IR sounders in the LEO + GEO experiment computed in 5º grid boxes.

To understand why there is a different GEO sounder impact between 06 and 12 UTC, the full observation suite is evaluated. Conventional observations from radiosondes and aircraft have a count minima at 06 UTC, producing a gap in the data information available for forecast error reduction. With their high temporal frequency, GEO sounders can fill that data gap and provide a beneficial impact that reduces forecast error.

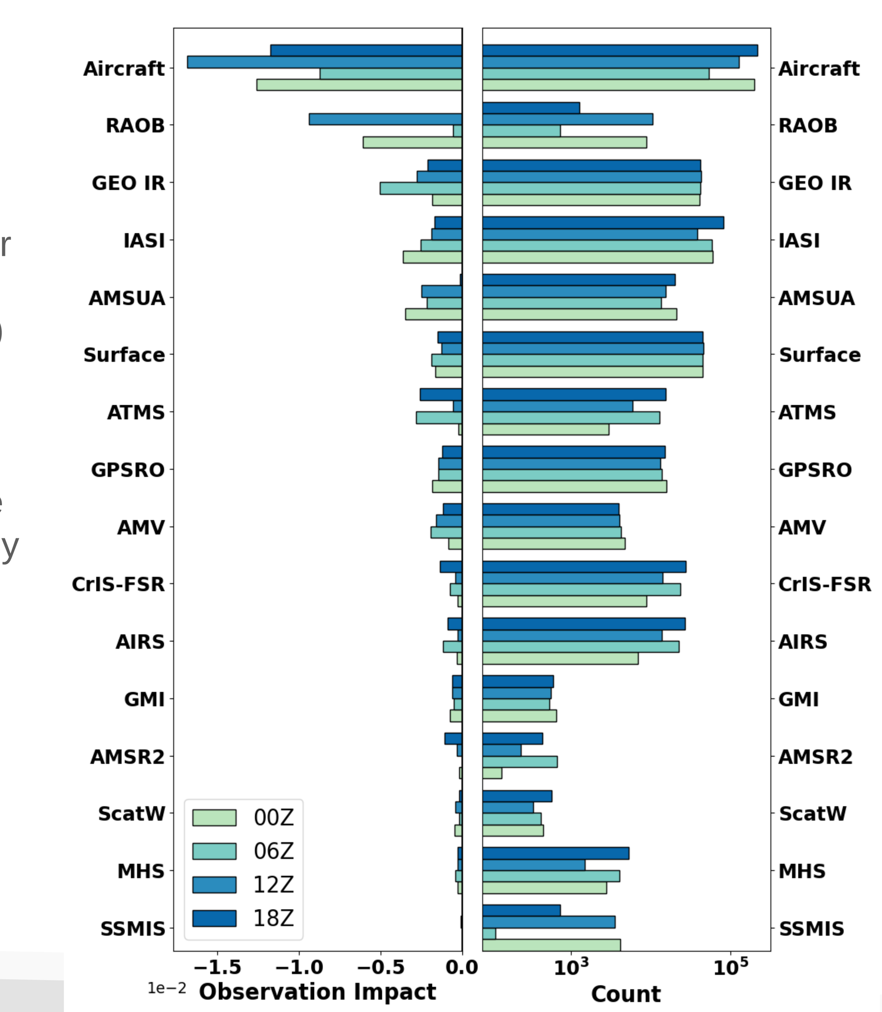

Figure 5: (left) FSOI per analysis as a function of instrument type calculated over CONUS for the 0000, 0600, 1200, and 1800 UTC analyses separately and (right) corresponding observation count per analysis. The instrument type ordering is according to the impact averaged across all analysis cycles. Over CONUS, the GEO IR instrument impact is dominated by the GeoXO Sounder. Computations were done for the LEO + GEO experiment.

References

McGrath-Spangler, E. L., N. C. Privé, B. M. Karpowicz, I. Moradi, and A. K. Heidinger, 2024: Using OSSEs to Evaluate GXS Impact in the Context of International Coordination. J. Atmos. Oceanic Technol., 41, 261–278, https://doi.org/10.1175/JTECH-D-23-0141.1.

Acknowledgements

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Learn more about the GeoXO Sounder (GXS)

Contact

Erica McGrath-Spangler
Erica.L.McGrath-Spangler@nasa.gov