Update on ROMEX in the Navy's Global System

[1]H. Christophersen (hui.w.christophersen.civ@us.navy.mil), [1]D. Tyndall, [2]J. Cossuth

[1]Naval Research Laboratory, Monterey, CA [2]Office of Naval Research, Arlington, VA

Summary

- The Radio Occultation Modelling Experiment (ROMEX) increases the RO data count to ~2 million per DA cycle, compared to ~400 K per DA cycle in the current ops system. Bending angle (BA) zonal innovation statistics remain similar but with approximately 6 times higher data count (Fig.1). The most significant BA impact occurs in the upper troposphere and lower stratosphere due to a good fit of the observation and relatively low assigned observation error. Above 30km impact height, BA shows minimal impact (Fig. 2-3).
- Assimilation of ROMEX data results in warming, moistening, and reduced winds in lower troposphere at the analysis time (Fig. 4), while the upper troposphere experiences opposite effect. This may worsen the warm, low-wind condition in the lower troposphere observed in the control run, but could slightly improve the dryness in that region.
- SPIRE RO has the largest FSOI impact, followed by COSMIC2, Yunyao, and PlanetIQ, with these providers offering larger data volumes that contribute to their larger impact (Fig.5). Generally, more data leads to a greater FSOI impact. The diurnal impact is more apparent for Chinese RO data (e.g. FengYun series) than others (Fig. 6).
- When verifying against independent observations, assimilating ROMEX data raises the standard deviation of first-guess departures for temperature-sensitive observations and lowers them for water vapor sensitive observations. (Fig. 7).
- Comparing to the ECMWF IFS analysis, assimilation of ROMEX RO generally improves the medium-range moisture forecasts (Fig. 8).
- Verification against ECMWF analyses or radiosondes shows that the substantial increase in ROMEX data assimilation degrades the medium-range forecasts for geopotential or temperature.

Background and Experiments

- The Global navigation satellite system (GNSS) Radio Occultation (RO) data is a key observational platform that significantly reduces forecast error in the Navy's model.
- Motivated by recent studies that showed little saturation in RO profiles for enhancing numerical weather prediction (NWP) (Privé et al. 2022), the International Radio Occultation Working Group (IROWG) under the Coordination Group for Meteorological Satellites (CGMS) of the World Meteorological Organization (WMO) initiated the ROMEX.
- A set of three experiments was conducted. The control run excludes RO data from SPIRE, GeoOptics, PlanetIQ, Tianmu, Yunyao and FengYun series. Note that the operational system ingests some SPIRE data acquired through NOAA and NASA commercial data purchase program.

Experiment Name	Description
Control	Assimilate RO similar to operational NAVGEM except data sources are from commercial and Chinese providers
ROMEX	Assimilate RO data from ROMEX including data from commercial and Chinese providers
NO_RO	Exclude all RO data

- The operational Naval Global Environment Model (NAVGEM) was employed at T681L60 (~19 km with a model top at 0.04 hPa)
- NAVGEM's data assimilation (DA) system is a dual-space strong constraint 4DVar hybrid system (Daley & Barker, 2000; Kuhl et al., 2013; Rosmond & Xu, 2006). The DA system routinely ingests about 4 million observations for each 6-hour DA cycle (Christophersen et al. 2023; Stone et al. 2020; Frolov et al. 2020).
- GNSS RO bending angles are assimilated via the Radio Occultation Processing Package (ROPP) 1D forward operator (Culverwell et al., 2015).

ROMEX Data Characteristics

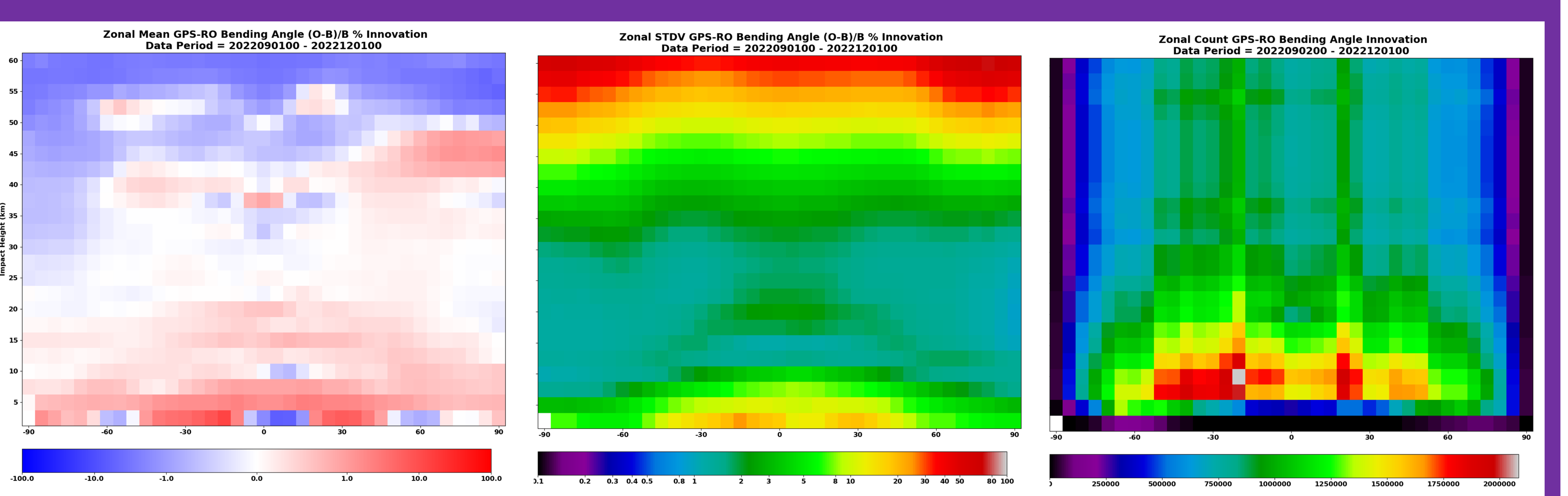

Fig.1: Zonal mean and standard deviation of (O-B)/B and data count for all ROMEX RO observations from September to November, 2022. O refers to the observation, B to the background.

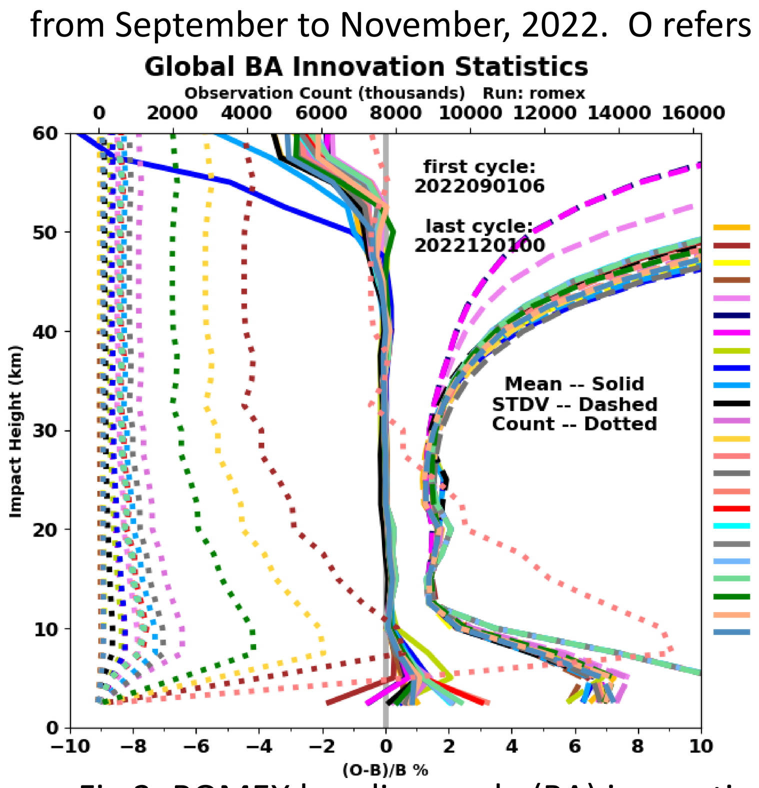

Fig.2: ROMEX bending angle (BA) innovation, normalized by the background BA ((O-B)/B), as a function of impact height (km) for all ROMEX missions from September to November 2022. O-observation, B-background.

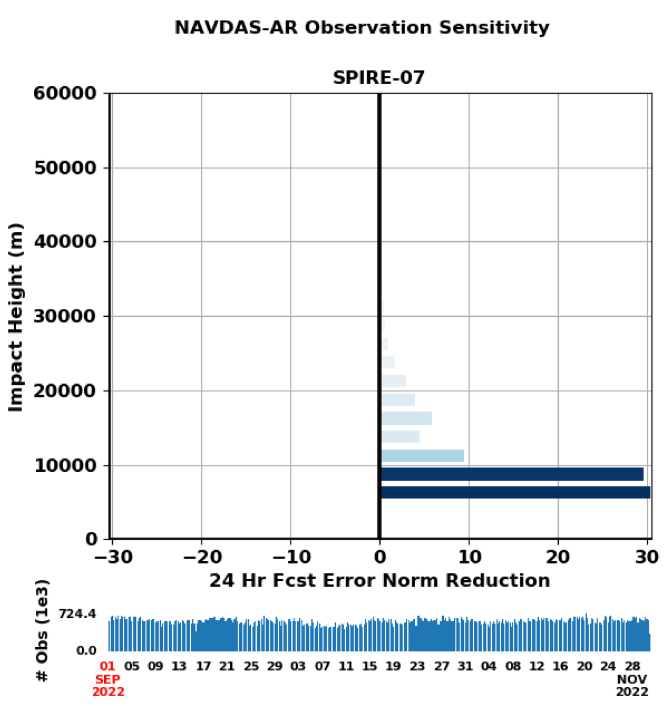

Fig.3: Total FSOI (J/kg) for bending angle from SPIRE (receiver range from 126-169) as a function of impact height (m) from September to November 2022.

ROMEX Impact on Model Analyses and Short-range Forecasts

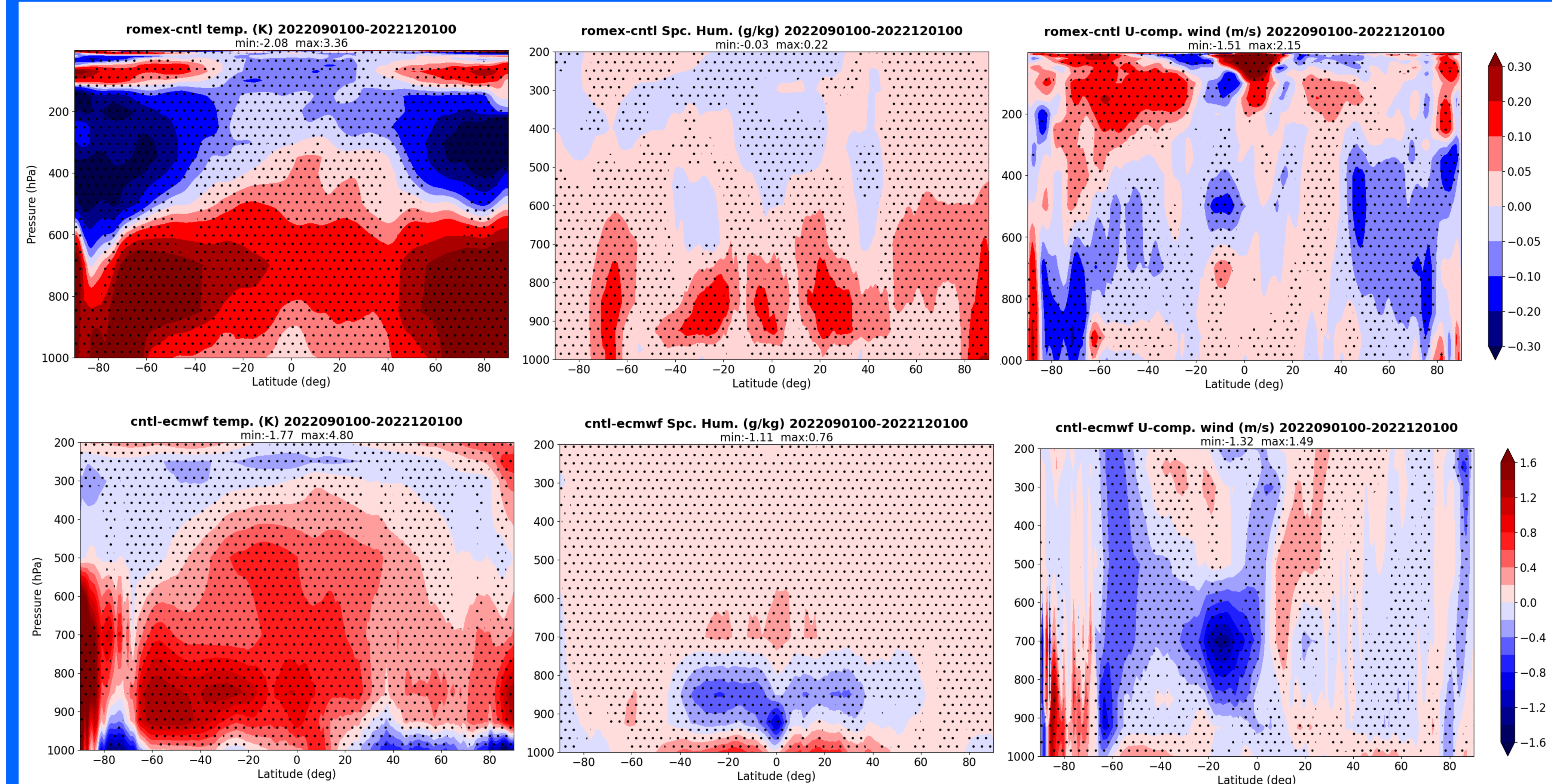

Fig. 4: Mean bias at the analysis time for temperature (K), specific humidity (g/kg), and meridional winds (m/s) (top) between ROMEX and control run, and (bottom) between the control run and ECMWF analyses. The dot signifies the mean different is statistically significant at the 95% level.

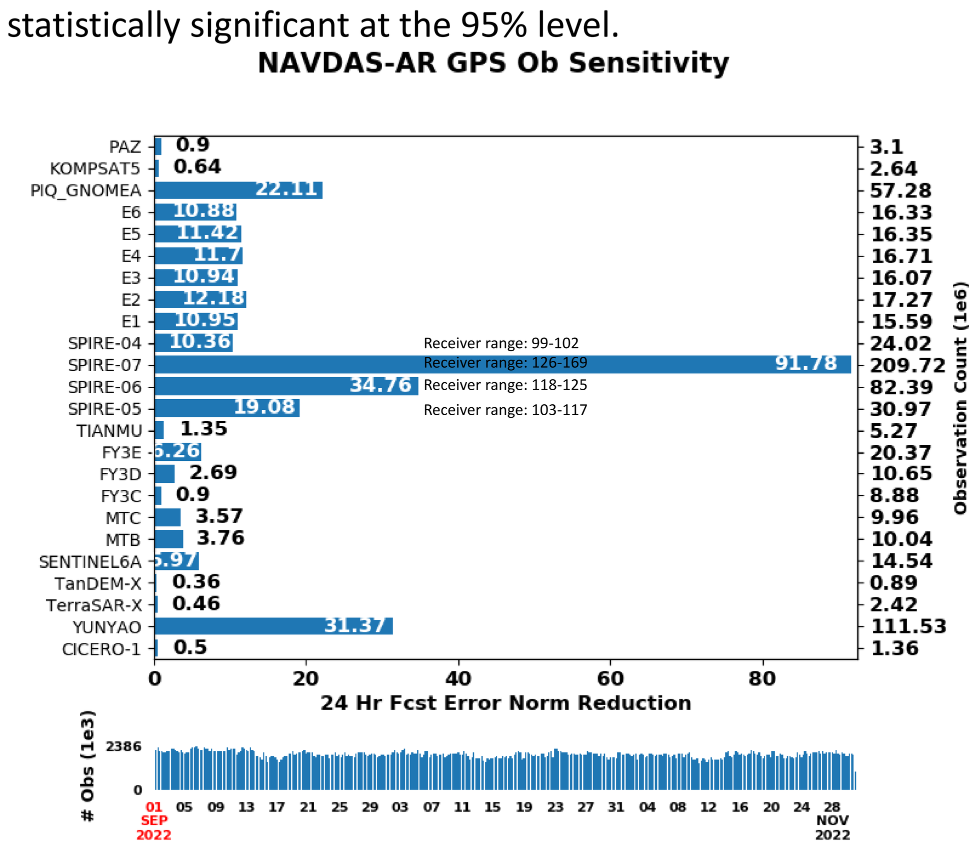

Fig.5: Total Forecast sensitivity to observation impact (FSOI, J/kg) for all the ROMEX missions from September to November 2022.

Fig.6: Total FSOI (J/kg), FSOI per observation (J/kg) and data count for bending angle from SPIRE, COSMIC2, YUNYAO, and FY3E as a function of data assimilation cycle hour from 1-11 September, 2022.

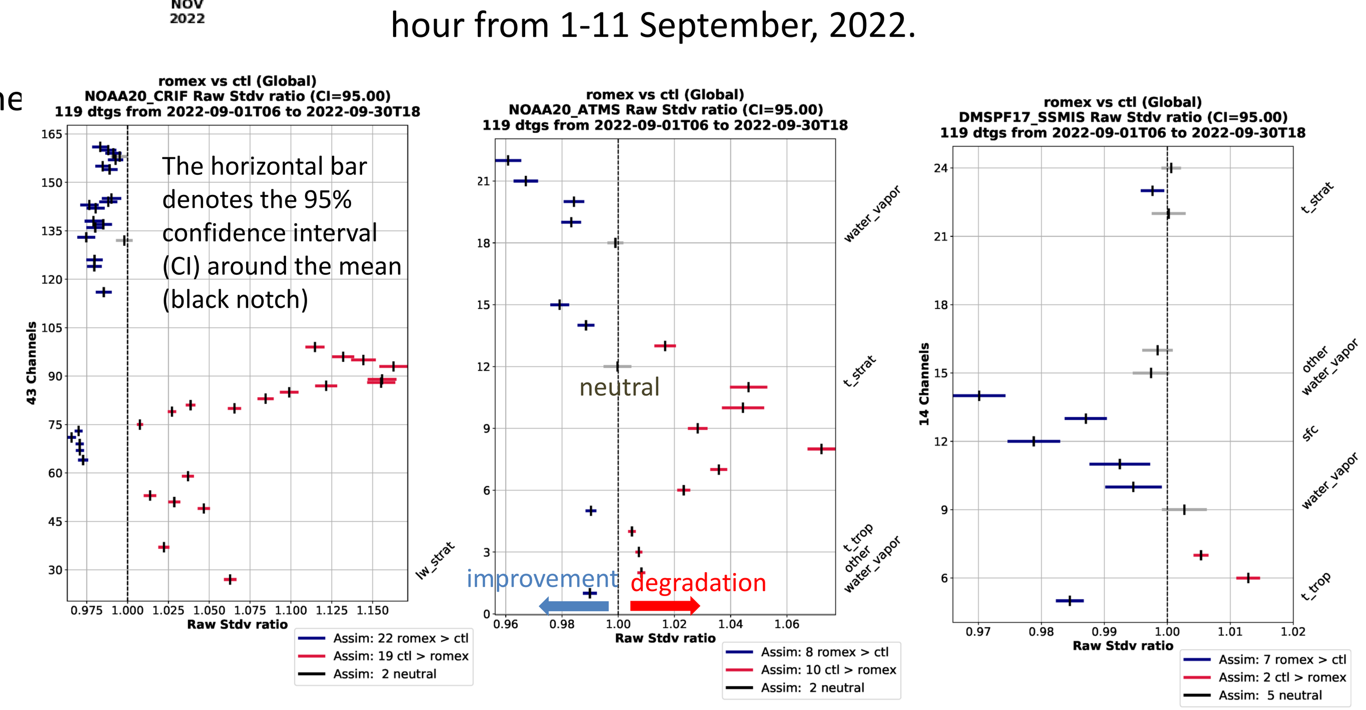

Fig.7: Ratio of the mean raw standard deviations of innovations (aka "fit to observations") for (left) CrIS NOAA20, (middle) ATMS NOAA20, and (right) SSMIS DMSP F17 between ROMEX experiment ("romex") and the control run ("ctl") for September to November 2022.

ROMEX Impact on Medium-range Forecasts

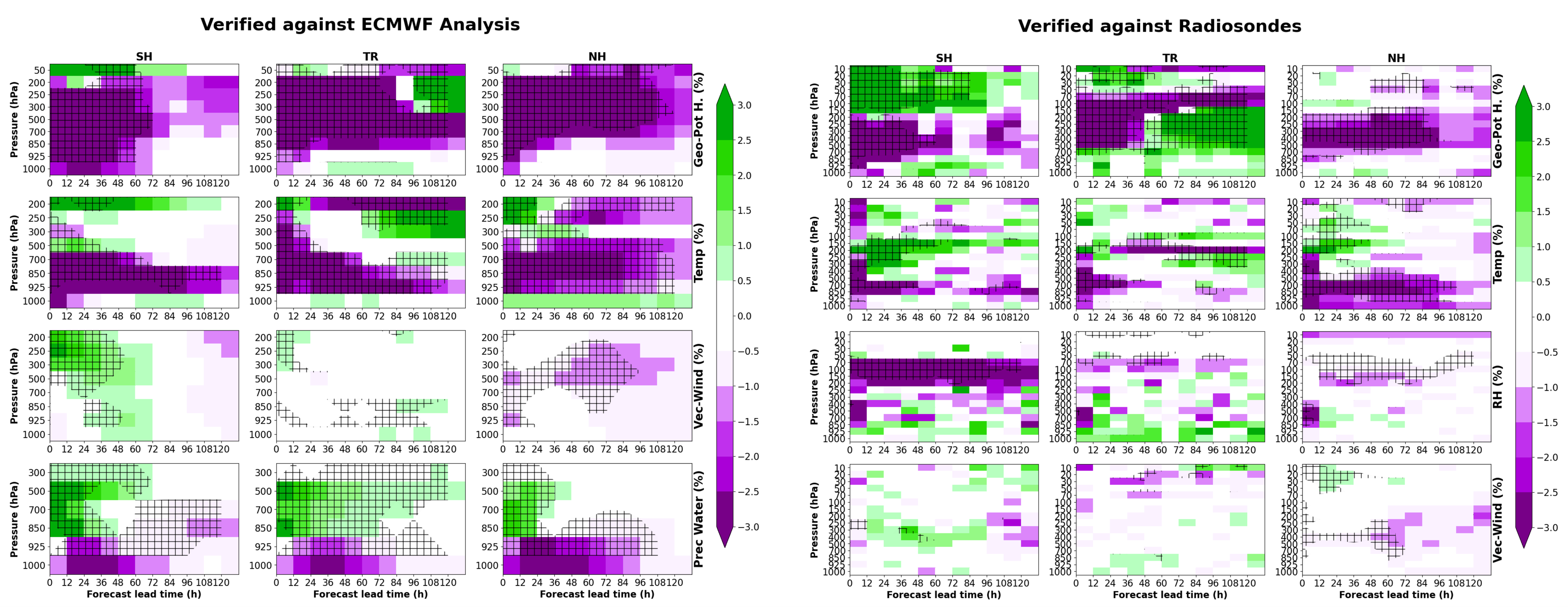

Fig.8: Relative forecast impact (shaded) for geopotential height, temperature, vector winds and precipitable water comparing the assimilation of the full set of ROMEX RO observations with the control experiment, which excludes RO observations from the commercial and Chinese providers. The relative impact is verified against (left) ECMWF analyses (b) radiosondes for Northern Hemisphere (NH, 20°–80°N), tropics (TR, 20°S–20°N), and Southern Hemisphere (SH, 20°–80°S) from September to November 2022. The relative impact is defined as $100 * \frac{RMSE_{ctl} - RMSE_{romex}}{RMSE_{ctl}}$, where RMSE is the root mean square error of the forecasts (e.g. winds) every 12 hours from the control and comparison experiment, computed against the verifying references. **Green colors indicate the assimilation of ROMEX observations improves the forecast skill**, while **purple colors signify assimilation of ROMEX observations degrades the forecast skill**. The hatched area shows that the impact is statistically significant at the 95% level.