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IMPACT OF SOLAR ACTIVITY ON FORECASTING THE UPPER ATMOSPHERE

ABSTRACT

This poster is an extract from Kodikara et at., (2021). The study presents a comprehensive comparison of the impact of solar activity on forecasting the upper atmosphere through assimilation of radio occultation (RO)-derived electron density (*Ne*) into a physics-based model (TIE-GCM) using an ensemble Kalman filter (KF). Globally abundant RO-derived *Ne* offers one of the most promising means to test the effect of assimilation on the model forecasted state on a global scale. This study emphasizes the importance of understanding how the assimilation results vary with solar activity, which is one of the main drivers of thermosphere-ionosphere dynamics. This study validates the forecast states with independent RO-derived GRACE (Gravity Recovery and Climate Experiment mission) *Ne* data. The principal result of the study is that the agreement between forecast *Ne* and data is better during solar minimum than solar maximum. The results also show that the agreement between data and forecast is mostly better than that of the standalone TIE-GCM driven with observed geophysical indices. The results emphasize that TIE-GCM significantly underestimate *Ne* in altitudes below 250 km and the assimilation of *Ne* is not as effective in these lower altitudes as it is in higher altitudes. The results demonstrate that assimilation of *Ne* significantly impacts the neutral mass density estimates via the KF state vector—the impact is larger during solar maximum than solar minimum relative to a control case that does not assimilate *Ne*. The results are useful to explain the inherent model bias, to understand the limitations of the data, and to demonstrate the capability of the assimilation technique.

DATA ASSIMILATION EXPERIMENTS

E1 Assimilate COSMIC-*Ne* during solar minimum (2008 March 4–8); and
E2 Assimilate COSMIC-*Ne* during solar maximum (2014 June 2–6).

COSMIC=Constellation Observing System for Meteorology, Ionosphere and Climate/Formosa Satellite 3. The two periods are quiet in geomagnetic activity (e.g., $Kp < 4$).

IMPACT OF THE ASSIMILATION BY LOCAL TIME

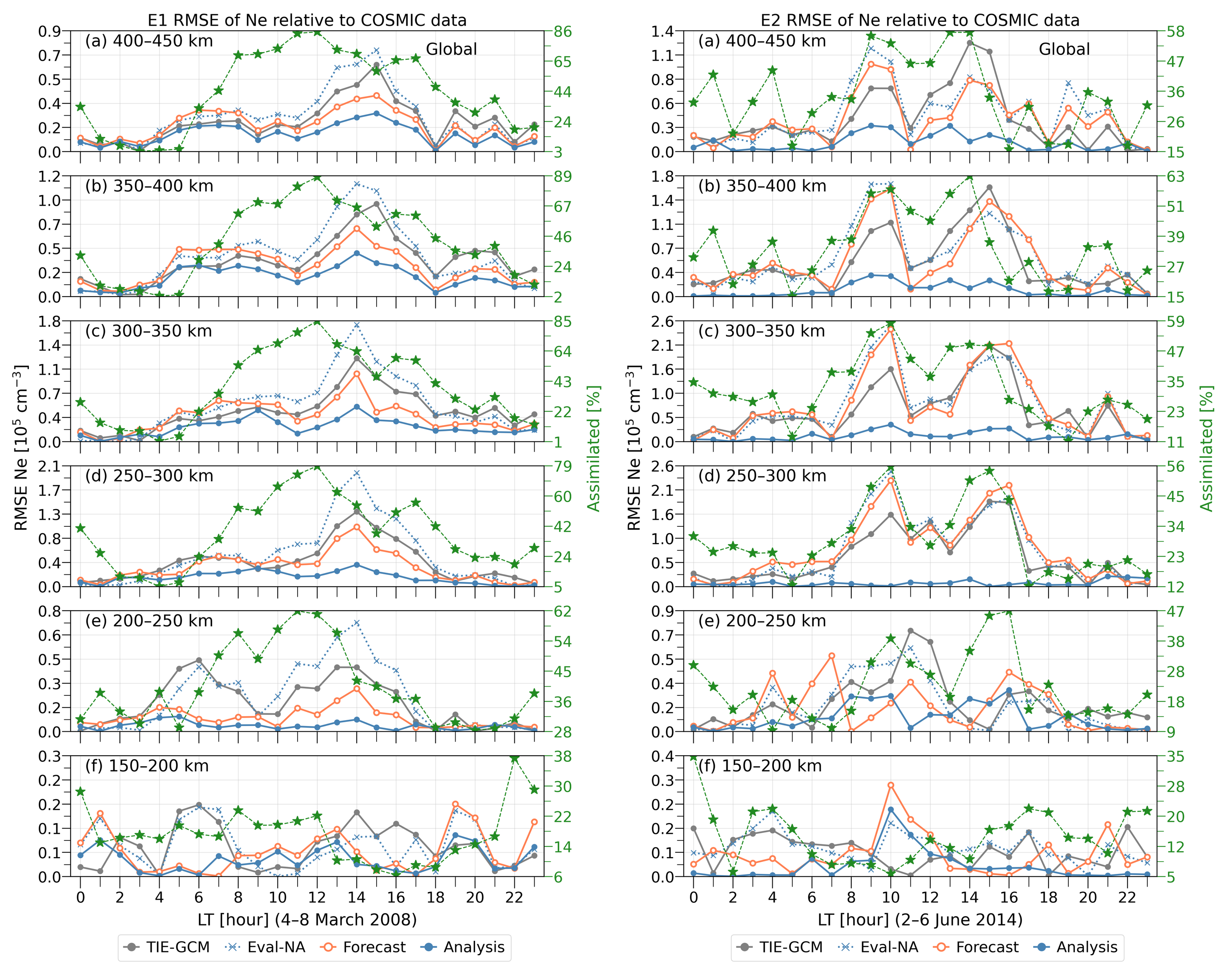

Figure 1: (a–f; E1 column-left) The root-mean-square error (RMSE) of *Ne* of the physics-based TIE-GCM (gray), Eval-NA (Evaluation-No Assimilation; blue-dotted), forecast (orange), and analysis (blue) relative to COSMIC-*Ne* in the specified altitude region for E1. The results are grouped by local time of COSMIC data and represent the global mean. (a–f; left column-right) The percentage of assimilated over total COSMIC-*Ne* observations in each LT-hour bin (green). (E2 column) Same but for E2.

IMPACT OF THE ASSIMILATION BY ALTITUDE AND LATITUDE

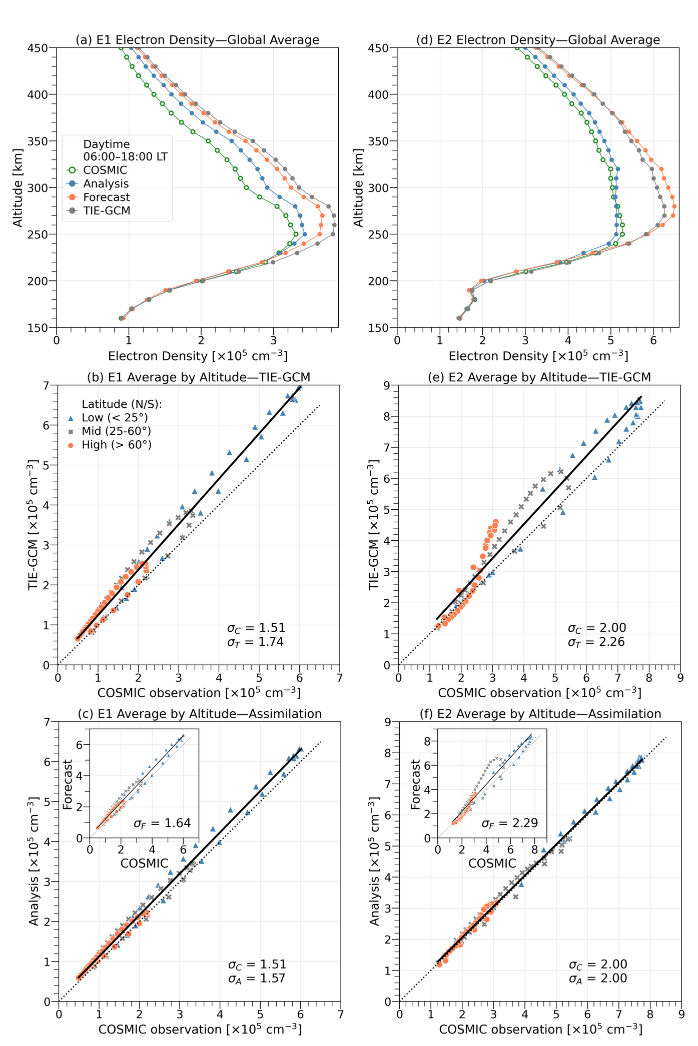

Figure 2: Vertical profiles of *Ne* corresponding to the daytime sector in experiments (a) E1 and (d) E2. (b, c, e, f) Statistical summary of *Ne* averaged in 10 km-altitude bins for (left) E1 and (right) E2. σ_C, σ_T, σ_A, and σ_F refer to the standard deviations (in units of $10^5\mathrm{cm}^{-3}$) of COSMIC, TIE-GCM, analysis, and forecast, respectively, considering the collective distribution across all latitudes. (c, f) The unit of COSMIC and forecast in the inset is $10^5\mathrm{cm}^{-3}$. The scale and unit of the insets are identical to that of their corresponding main figure. The solid line is a linear fit considering the collective distribution.

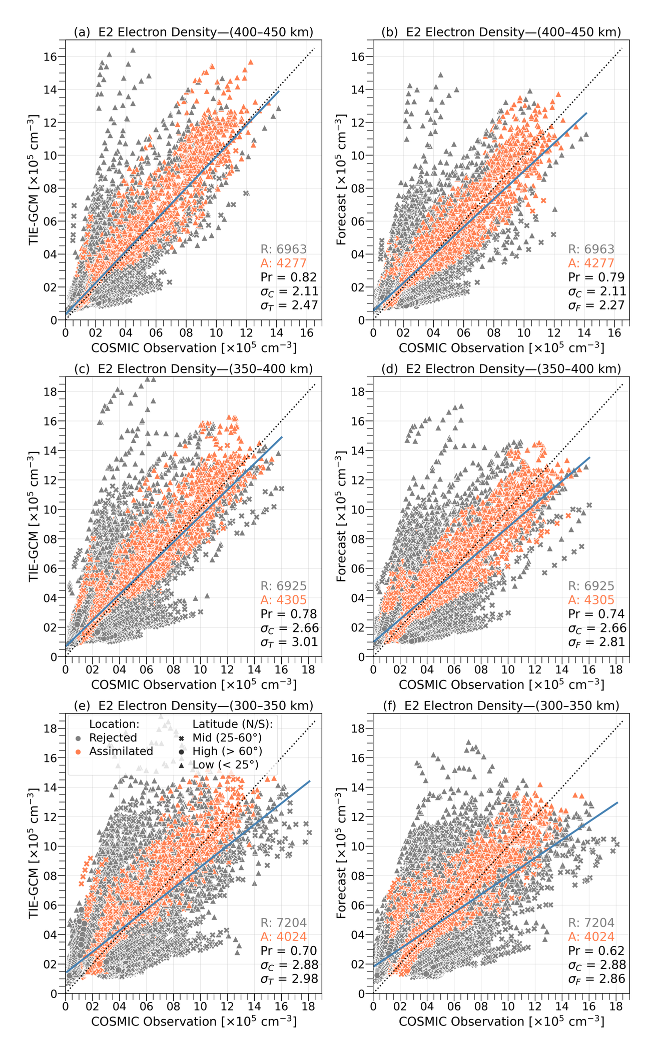

Figure 3: (a–f) A multidimensional scatter plot comparing COSMIC-*Ne* with (left column) TIE-GCM and (right column) forecast in E2. The data points in orange (gray) indicate whether the particular COSMIC observation was assimilated (rejected) in the next assimilation cycle to produce the analysis state. The number of rejected (assimilated) observations in the distribution are noted as R (A). Pr is the Pearson correlation coefficient between distributions specified in the abscissa and ordinate. σ_C, σ_T, and σ_F give the standard deviations (in units of $10^5\mathrm{cm}^{-3}$) of COSMIC, TIE-GCM, and forecast, respectively. The solid blue line is a linear fit.

THE BIAS IN THE ASSIMILATION RESULTS

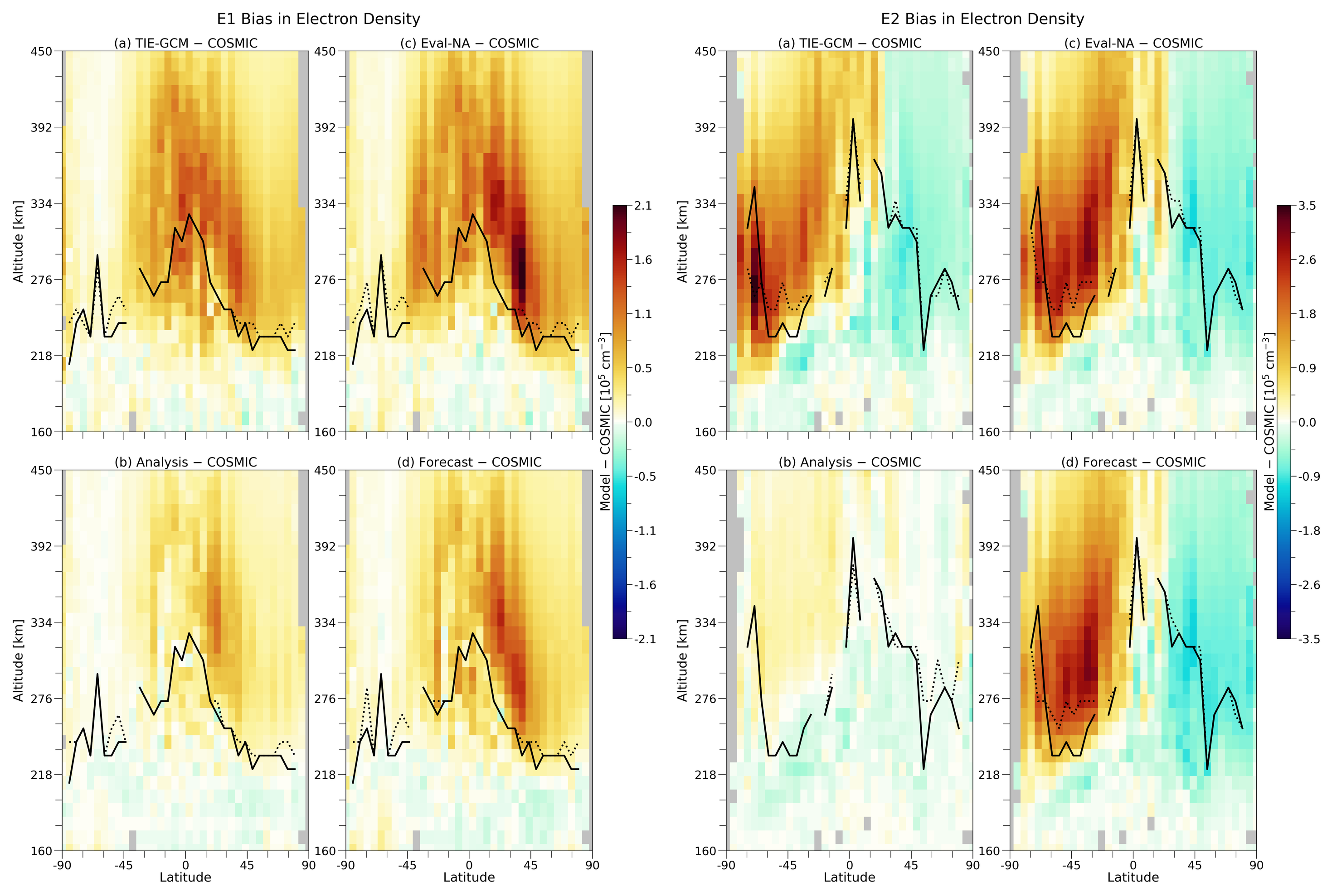

Figure 4: (a–d; left E1 columns) The geographic latitude (positive = North; negative = South) and altitude distribution of the difference between model estimated *Ne* and COSMIC-*Ne*. The black solid (dotted) line shows the height of maximum *Ne* for COSMIC (model) in each latitude column. The height of maximum *Ne* is not given for any latitude column with at least one bin with no data (gray areas). (right E2 columns) Same but for E2.

COSMIC-GUIDED FORECASTS COMPARED TO GRACE DATA

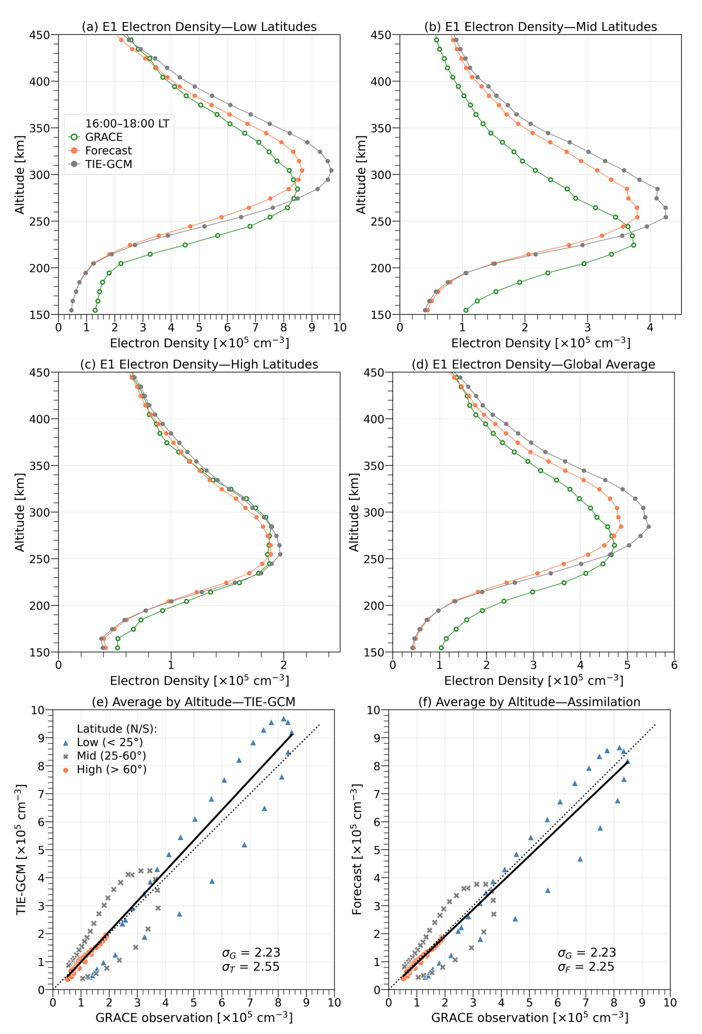

Figure 5: Results of E1 compared to independent GRACE data. (a–d) Vertical profiles of *Ne* at the specified latitude region. (e–f) Statistical summary of *Ne* averaged in 10 km-altitude bins. σ_G, σ_T, and σ_F refer to the standard deviations (in units of $10^5\mathrm{cm}^{-3}$) of GRACE, TIE-GCM, and forecast, respectively, considering the collective distribution across all bins. The solid line is a linear fit considering the collective distribution.

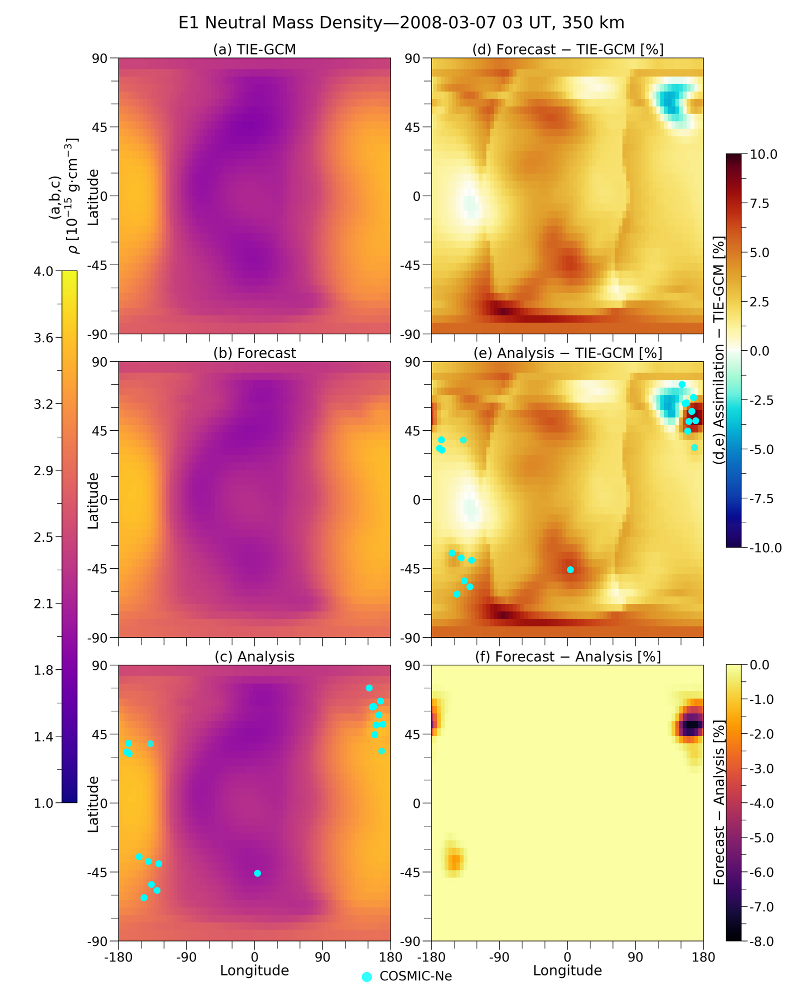

Figure 6: A snapshot of the impact of the assimilation of COSMIC-*Ne* on neutral mass density (ρ) for E1 at the specified time and altitude. The color-bar on top-right shows the percentage difference between (d) forecast and TIE-GCM, and (e) analysis and TIE-GCM. (f) The percentage difference between forecast and analysis. The blue dots indicate the locations of assimilated COSMIC-*Ne* profiles at the specified altitude within -2.5 and 0.5 hours of the specified time.

INFLUENCING THE NEUTRAL DYNAMICS

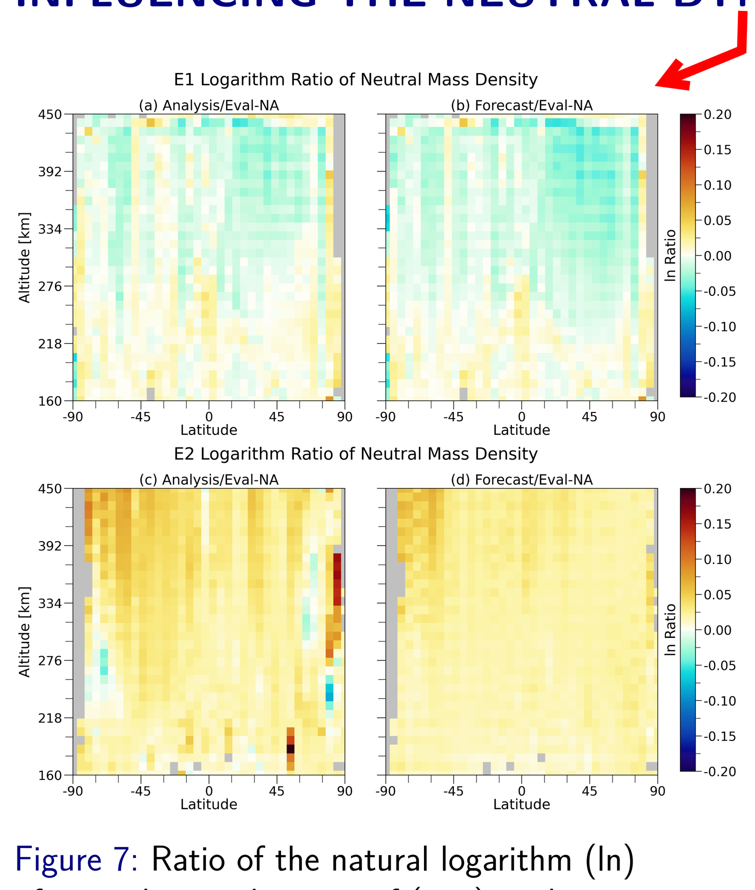

Figure 7: Ratio of the natural logarithm (ln) of neutral mass densities of (a, c) analysis, and (b, d) forecast to Eval-NA. The results here represent the longitudinal average as a function of geographic latitude and altitude for experiments (a, b) E1, and (c, d) E2.

KEY POINTS

1. Investigates the impact of solar activity on forecasting through assimilation of COSMIC-*Ne* into a physics-based upper atmosphere model.
2. The agreement between hourly forecasted *Ne* and data is better during solar minimum than solar maximum.
3. The assimilation reduces RMSE of *Ne* estimates much more significantly during the high solar activity period.
4. The assimilation of COSMIC-*Ne* into TIE-GCM significantly influences the neutral dynamics of the thermosphere.

FUTURE WORK

The experiments mainly focused on the assimilation accuracy during two different solar activity periods. More work needs to be done to identify and improve model bias due to external forcing—especially high solar activity above 120 sfu. More specifically, research into the impact of external forcing on the persistence skill of these forecasts will be useful, among others, to enhance our current forecasting capabilities. Assimilation of other data, for example, ground-based remote sensing measurements of thermospheric neutral winds and temperature could also help unravel some difficulties associated with forecasting the upper atmosphere.

Reference:

Kodikara, T., Zhang, K., Pedatella, N. M., & Borries, C. (2021). The impact of solar activity on forecasting the upper atmosphere via assimilation of electron density data. Space Weather, 19, e2020SW002660. https://doi.org/10.1029/2020SW002660

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