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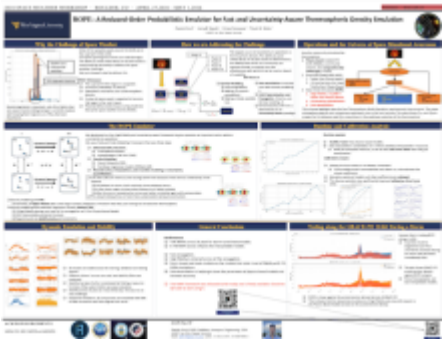
In recent years, the interest of operators in sending satellites in the low Earth orbit atmosphere (LEO) has risen and LEO assets are expected to reach $1.8 trillion by 2035. Thus, real-time intelligent maneuvering has become of primary interest for stakeholders.
The largest source of uncertainty for operators in LEO is thermospheric density, which is deeply nonlinear due to the Sun's activity. To address this challenge, we have built a Reduced-Order Probabilistic Emulator (ROPE) framework, a data-driven complement to physics-based models like TIE-GCM and empirical models like NRL-MSIS-2.1. Physics based models, despite being of high fidelity, present large computational cost and challenging uncertainty quantification for operations. Empirical models, although computationally efficient, do not directly provide uncertainty quantification.

ROPE is a data-driven framework compressing global three-dimensional density fields into a compact latent representation using various encoding methods preserving essential structures and variability.
The first modeling strategy we use in latent space employs an autoregressive SINDyc, which explicitly identifies dynamics. Within this framework we observe a MAPE of about 6% for a 5-day dynamic forecast from 1996 to 2009.
To further enhance robustness and generalization, and to better capture geomagnetically active intervals, ROPE employs a neural-network-based meta-modeling framework reaching approximately 5% MAPE over the dataset. The resulting system delivers rapid, uncertainty-aware thermospheric density forecasts suitable for operational drag propagation and space traffic management pipelines.
Complementary to the data driven framework based on TIE-GCM, we leverage data assimilation to retrain using observationally informed latent states containing some physics that measurements incorporated.



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