Validating and Improving a Realistic Ionospheric Truth Model for Observing System Simulation Experiments of HF Propagation

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ORION SPACE SOLUTIONS

What is an OSSE?

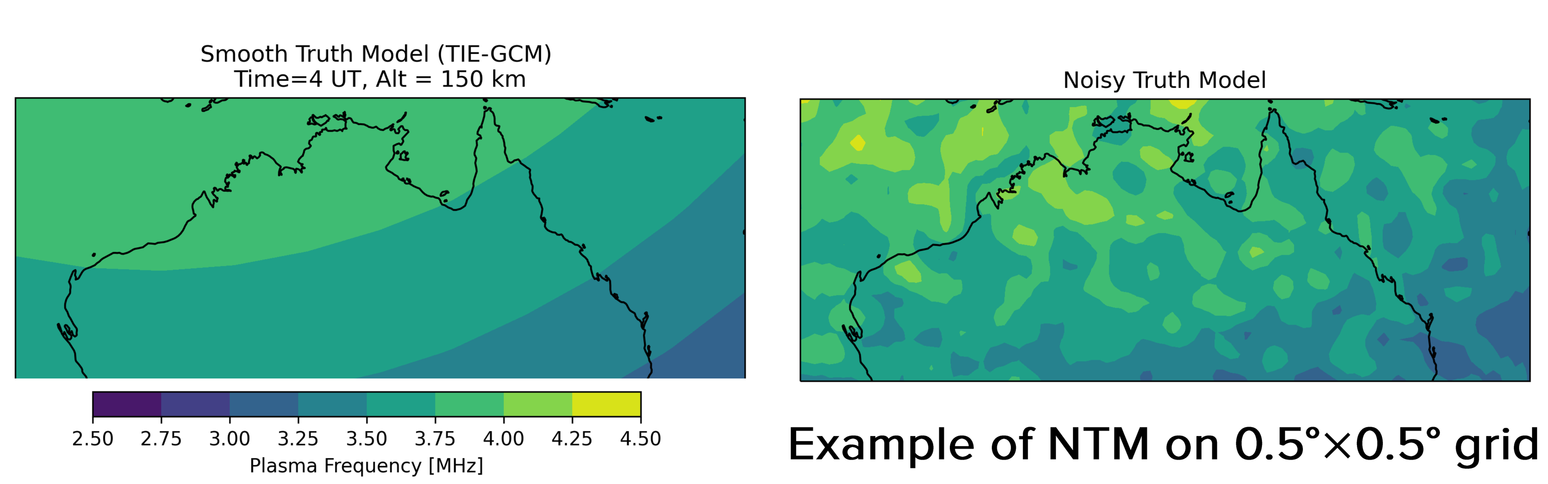
Decision makers are often tasked with choosing how many sensors to deploy, of what types, and in what locations to meet a given operational or scientific outcome. An **Observing System Simulation Experiment (OSSE)** is a numerical experiment which can provide critical decision support to these complex and expensive choices. There are three steps in an OSSE:

1) an observation system consisting of any combination of instruments such as ionosondes, GPS ground stations, or satellite-based RO is specified and the measurements are simulated using the truth model which contains the electron density at every location and time.
2) Second, these simulated measurements are provided to an assimilator which uses them to update a background model and create an analysis.
3) Lastly, the analysis and the background model are compared to the truth model.

The degree to which the analysis improves relative to the background indicates the value of those measurements. This process can be repeated for multiple combinations of instruments to compare the relative impact of different data sets. This impact can be paired with the cost of these datasets to estimate the ionospheric specification "bang" for a real-life buck.

Noisy Truth Model

A key part of an OSSE is having a realistic truth model or 'nature run'. Many ionospheric OSSEs use physics-based models as truth models. This can lead to overly optimistic assessments of a sensor architecture. For example, an OSSE using a smooth truth model will show improvements between two sensor locations even though no measurements are taken there because the truth model is well-approximated by the interpolant. Since the real-life ionosphere is more variable and is not well-modeled by an interpolant, this is an optimistic assertion of the improvement. It is therefore crucial to have a truth model with realistic variances to ensure accurate OSSE results. **It is impossible to know if a sensor system can find small-scale features if there are no small-scale features to find in the truth model.** Prior work has developed a noisy truth model (Hughes et al., 2022) or NTM. This work validates the NTM using data from AFCAP Experiment 2.

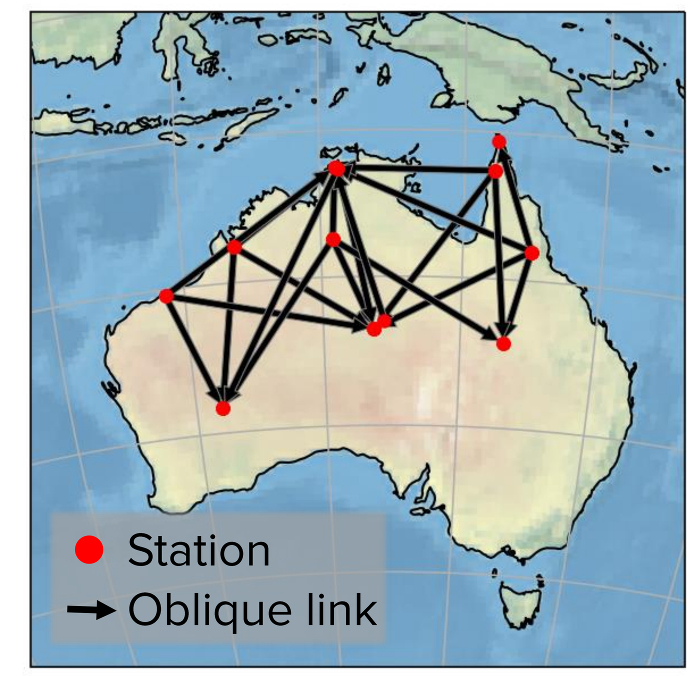


Example of NTM on 0.5°×0.5° grid

Hughes, J., et al. (2022). On constructing a realistic truth model using ionosonde data for Observation System Simulation Experiments. *Radio Science*, 57, e2022RS007508. https://doi.org/10.1029/2022RS007508

AFCAP Experiment 2

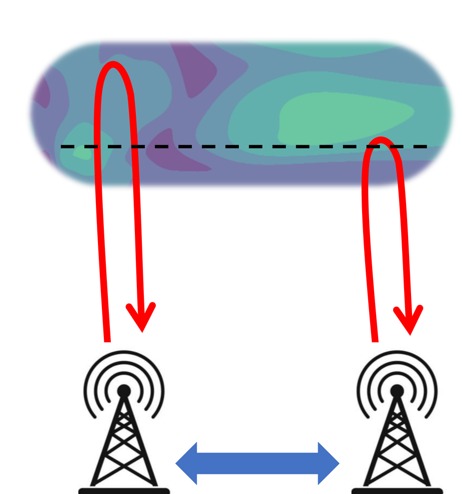
The US **Air Force Coverage and Analysis Program (AFCAP)** experiments are multimillion dollar campaigns to perform detailed observing system experiments (OSEs) of the ionosphere. We use vertical and oblique ionosonde observations from **AFCAP experiment 2 (AE2)** in Australia, June 29th, 2019, as an initial validation of the NTM.

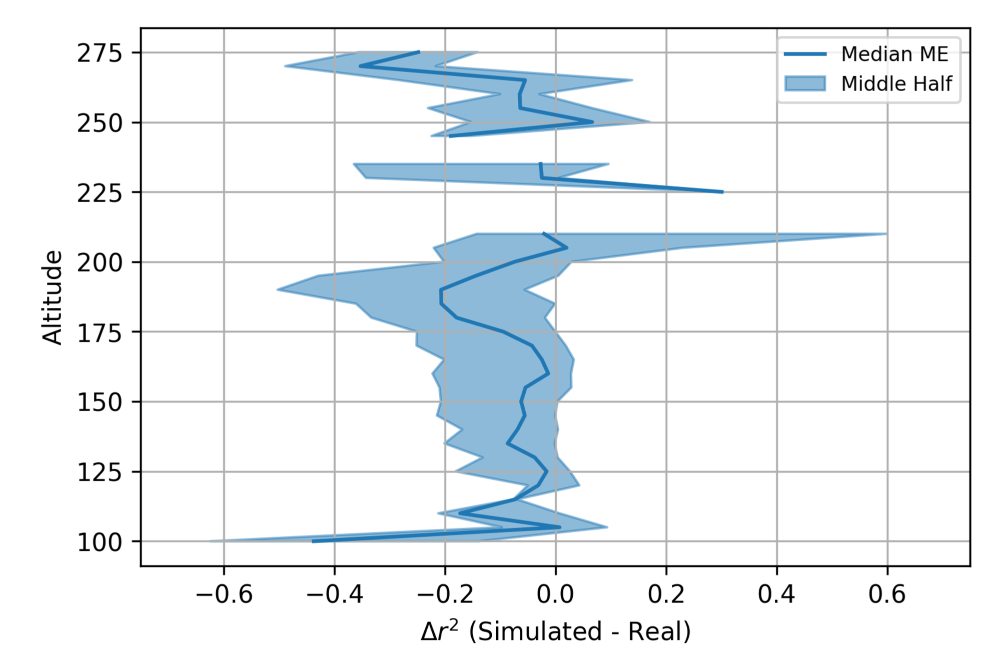


Comparison to AE2 Vertical Soundings

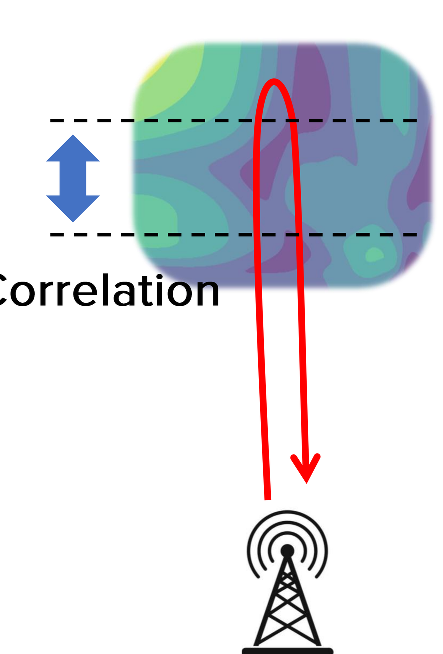
Vertical ionosonde measurements of electron density from AE2 are compared to NTM electron densities to validate the NTM's representation of small-scale variability in the bottomside ionosphere.

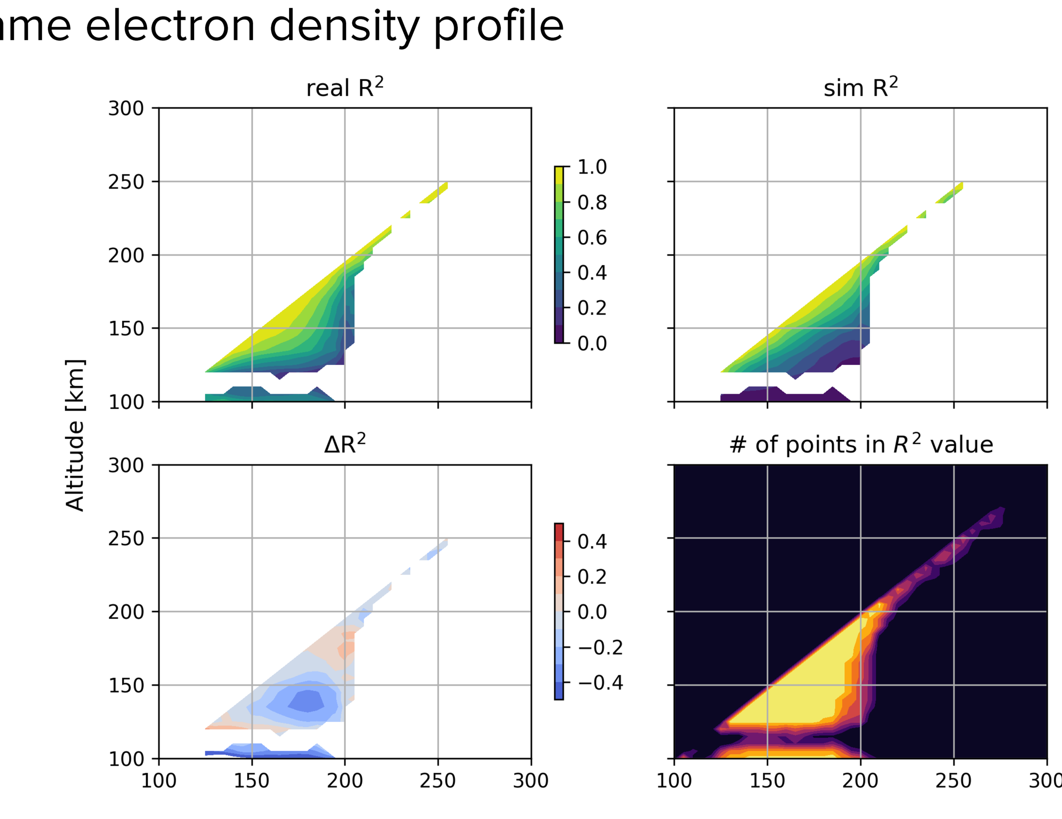
Horizontal correlation of electron density deviation at the same altitude and time between two ionosondes





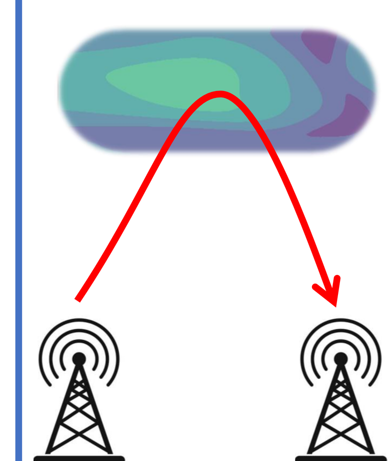
Vertical correlation of electron density deviation between different altitudes within the same electron density profile

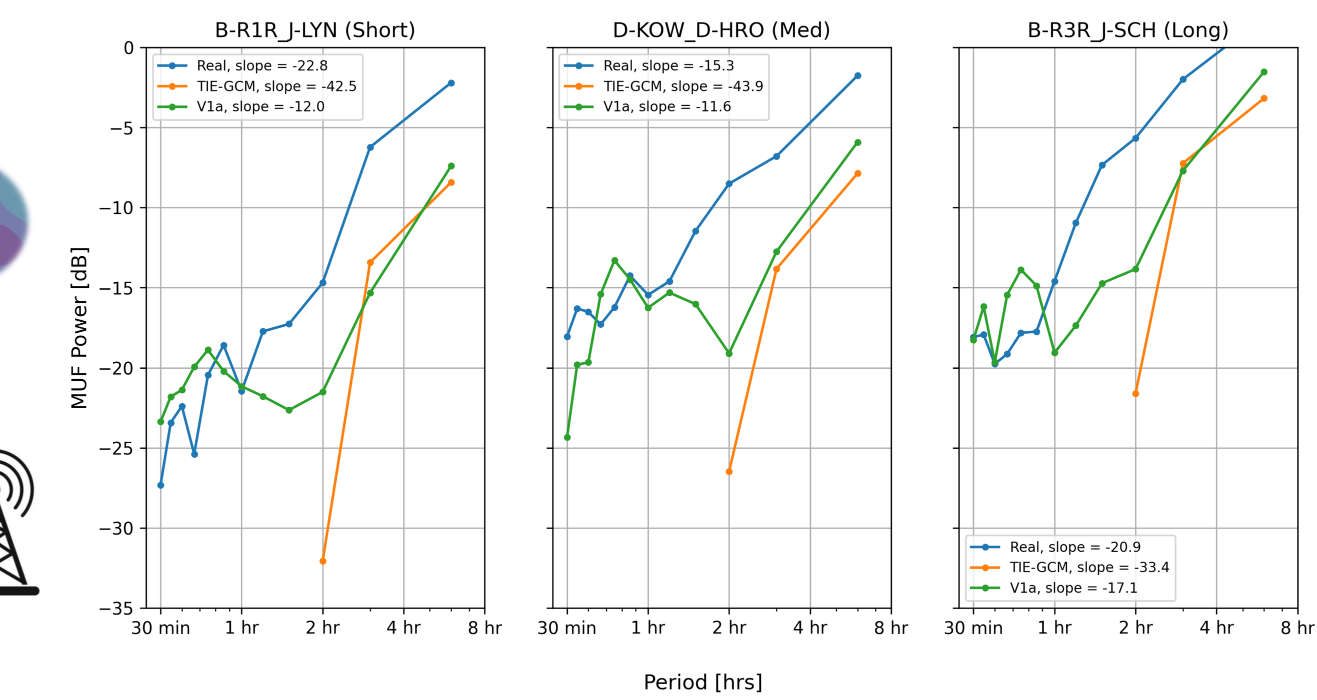




Comparison to AE2 Oblique Soundings

The maximum useable frequency (MUF) is determined from AE2 oblique ionograms and simulated for TIE-GCM and the NTM via HF ray-tracing. The spectra of the MUF throughout the whole day are compared as a preliminary test of the NTM's ability to capture small-scale variability relevant to HF propagation.



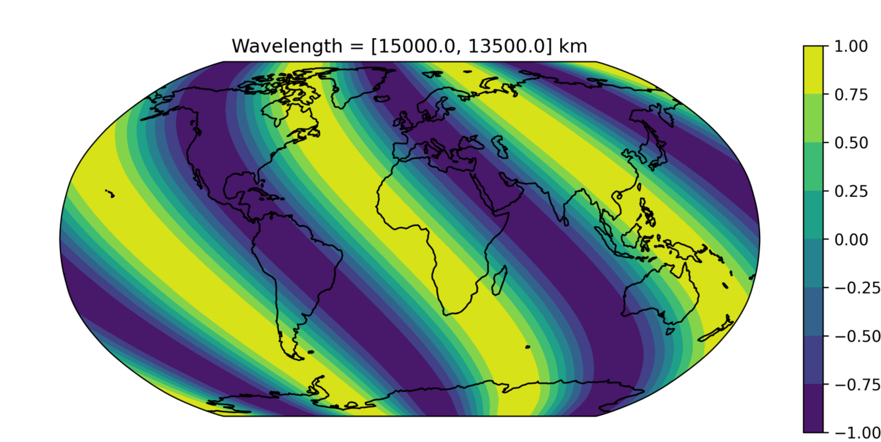


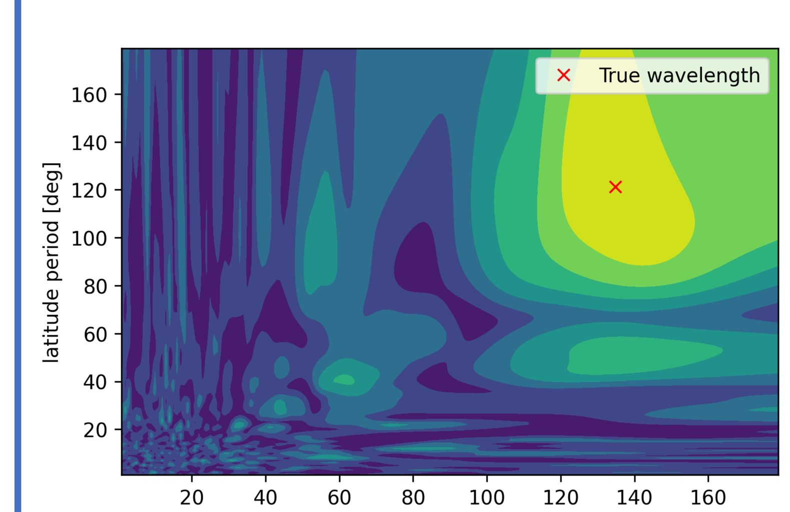
Status and Planned Improvements

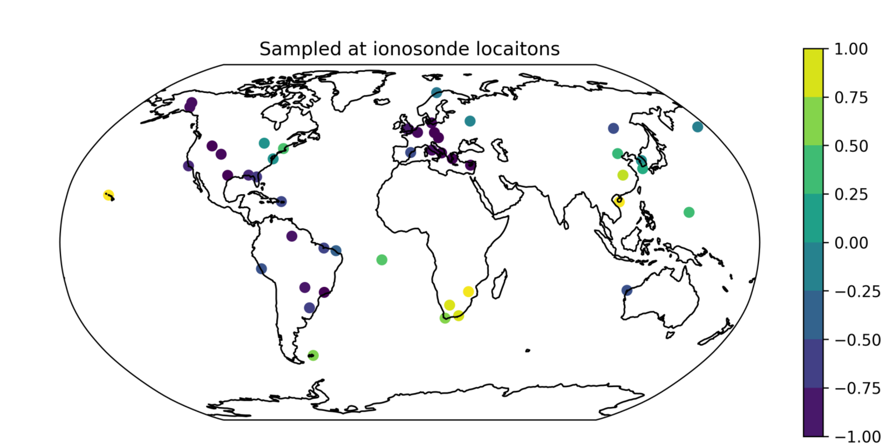
A score is assigned to indicate how well the current NTM represents reality for these comparisons (TIE-GCM baseline is 0% and AE2 data is 100%).

	Vertical Correlation			Horizontal Correlation			Spectral Content		
	AE2 Data	TIE-GCM	NTM	AE2 Data	TIE-GCM	NTM	AE2 Data	TIE-GCM	NTM
Value	0.62	0	0.49						
Error Value	0	-0.62	-0.13	0	0.79	0.13	0	33.21	12.73
Score	100.00	0.00	79.03	100.00	0.00	83.54	100.00	0.00	61.67

The next-generation NTM will use a multi-dimensional **Lomb Scargle Periodogram** to represent phenomena that are spatially and temporally coherent (sporadic E, traveling ionospheric disturbances, and more)







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