Sporadic E Modeling Using Convolution Neural Networks and Radio Occultations

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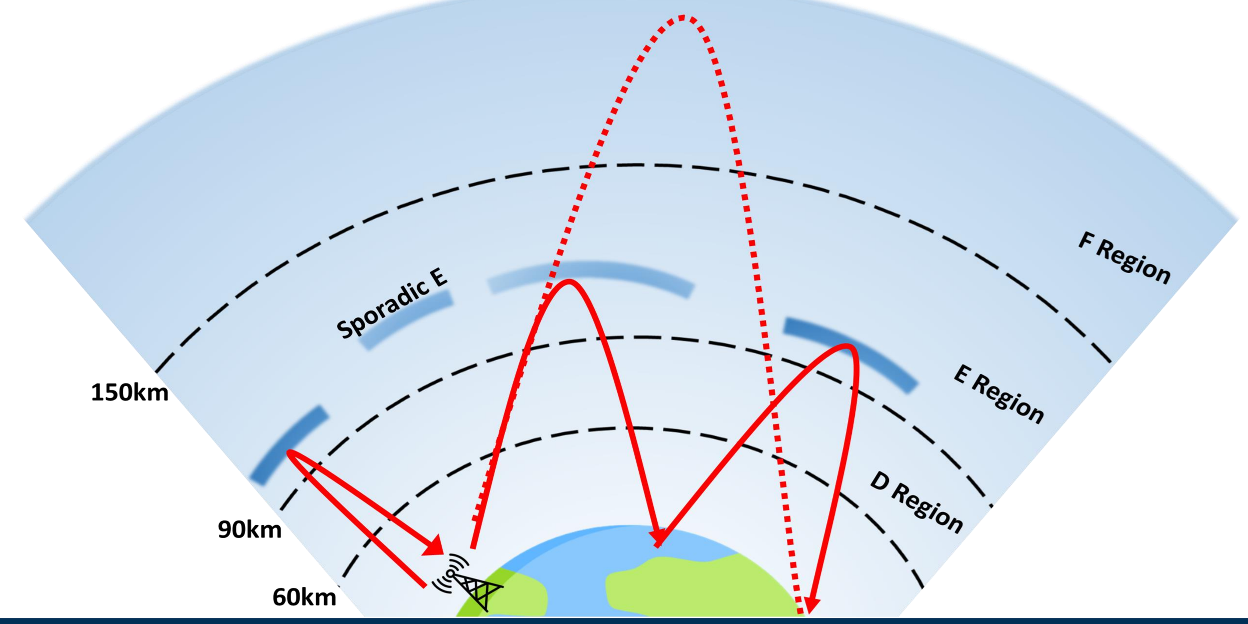
DATA-22

Abstract

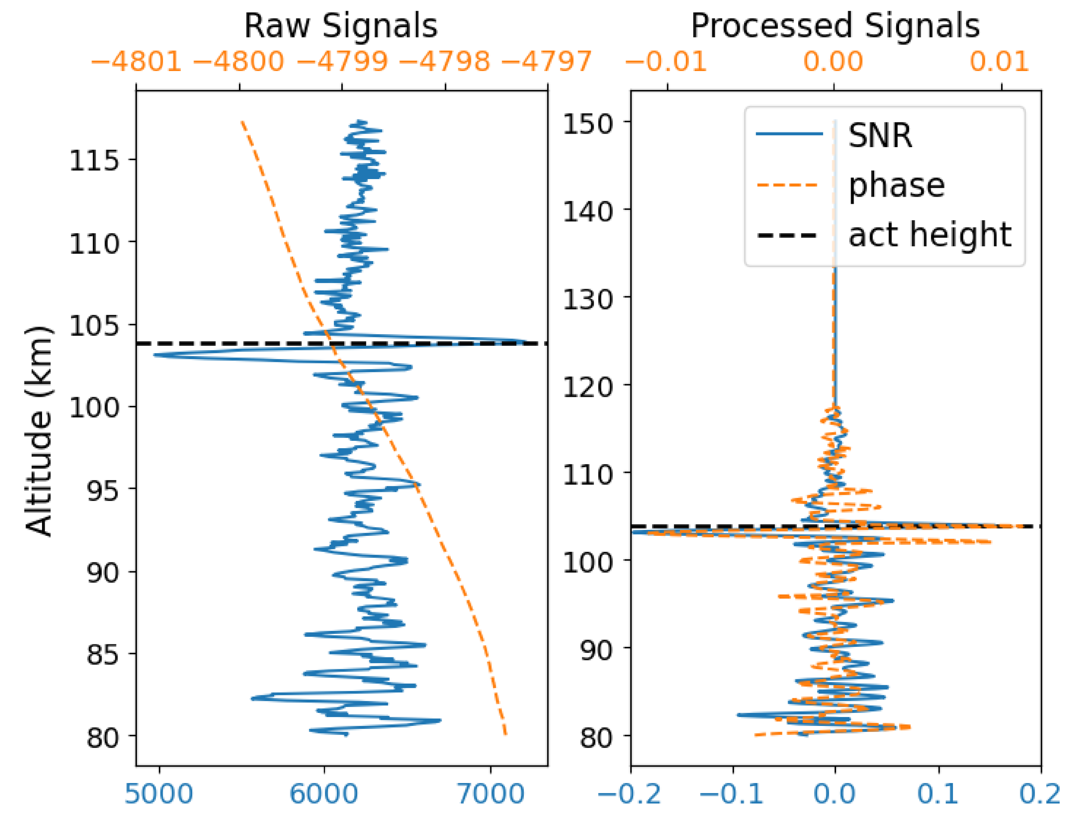
Sporadic E (Es) manifests itself as regions of enhanced ionization, occurring primarily at altitudes of 90-130 km above Earth's surface. These irregularly ionized layers can reflect or degrade radio waves propagating through the ionosphere and impact applications such as satellite and high frequency (HF) communications, Global Navigation Satellite System (GNSS) navigation and positioning, and over-the-horizon radar (OTHR). In order to effectively operate in these complex electromagnetic environments, a global understanding and accurate characterization of Es is critical. This work develops models to detect and characterize Es using convolutional neural networks (CNN). In training the networks, data from six GNSS radio occultation (RO) missions over the years of 2008 to 2022 are used as the input features while ionosondes are used as the target variables. The learned model can then be applied to any GNSS-RO data to produce a global prediction of Es.



Data

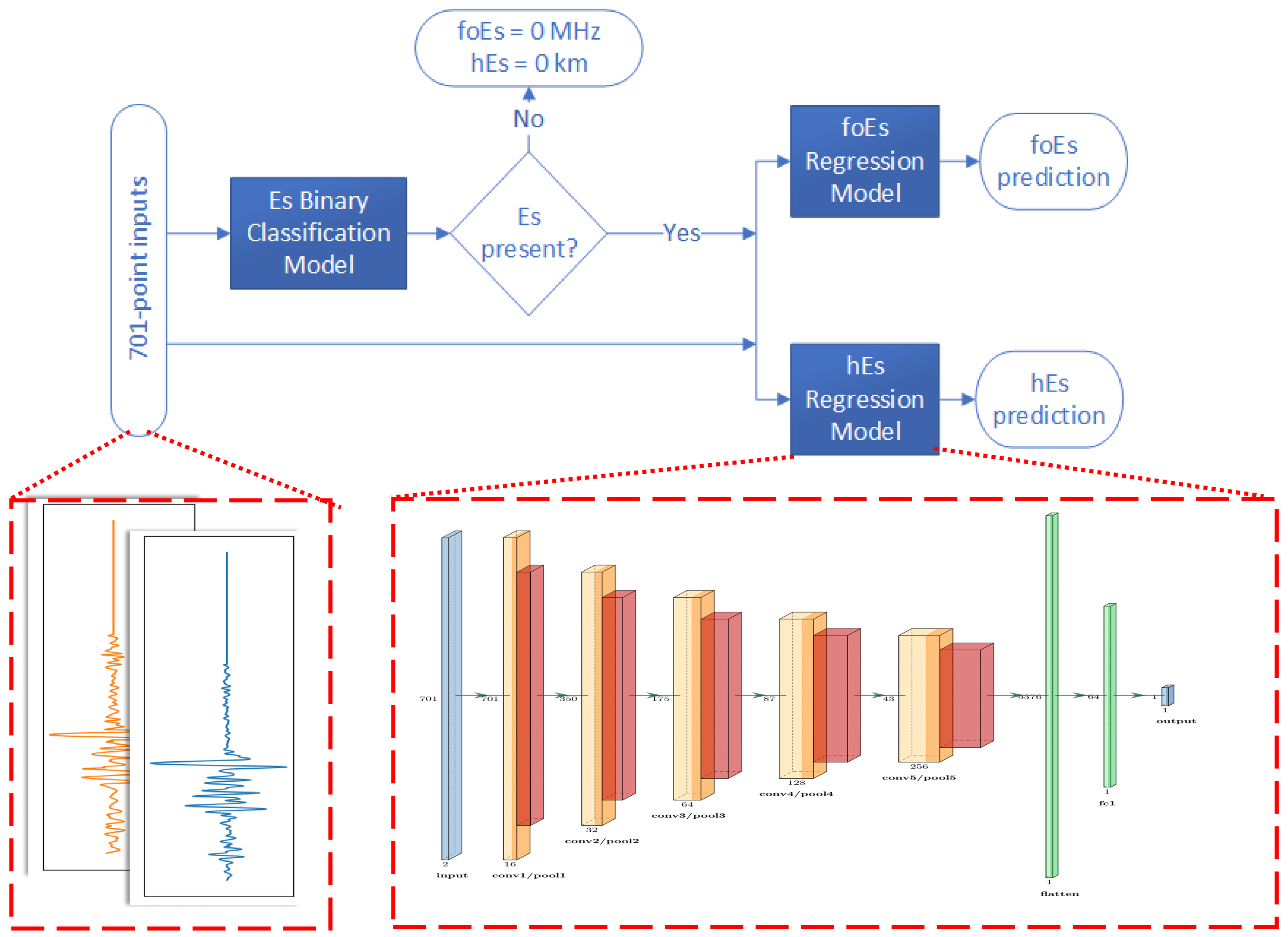
RO missions use satellites in LEO to receive signals from GNSS satellites in MEO. However, these measurements don't directly give Es characteristics (e.g., intensity, height), so they must be inferred. To make this inference, ionosondes are used to provide the ground truth to compare against.

In preprocessing the data, a 150-km and 30-min window is used to join RO and ionosonde data. The RO SNR data is centered and divided by its mean, while the RO phase data is detrended using a 2.5 km window.



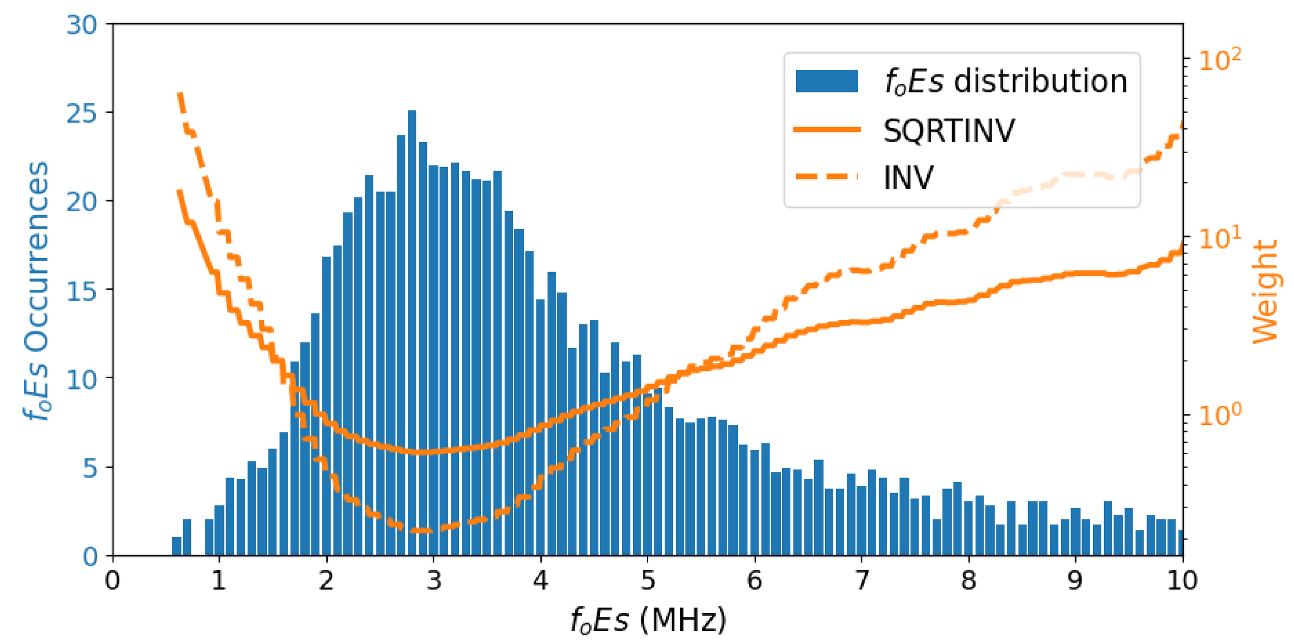
Machine Learning Model

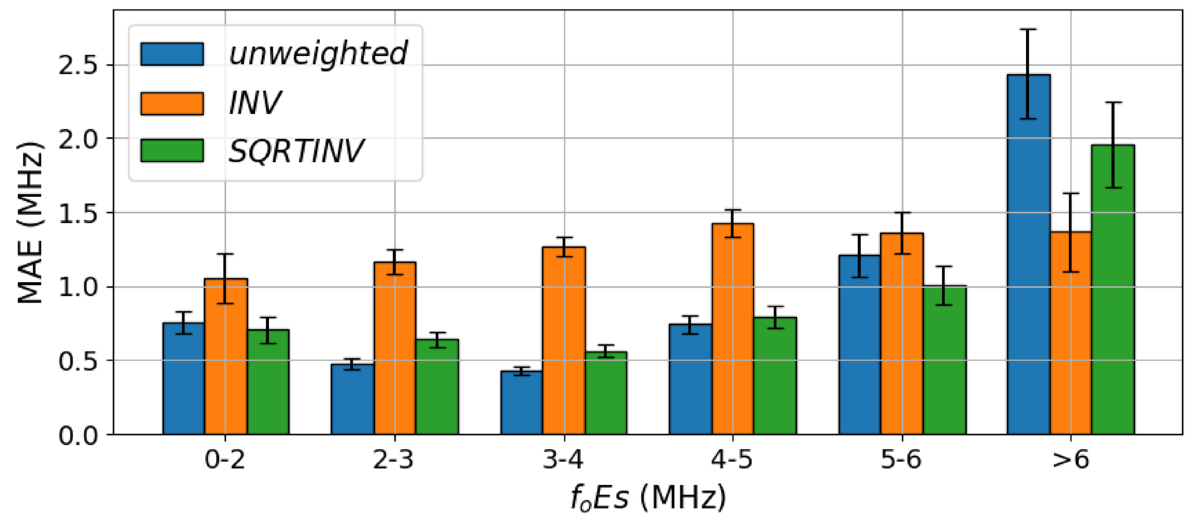
CNNs are used to develop both binary classification and regression models. The binary classification model is used to determine if Es is present, while the regression models are used to estimate values for the intensity and height of the layers. These models can then be chained together for an end-to-end prediction of Es from a RO measurement.



Class Imbalance

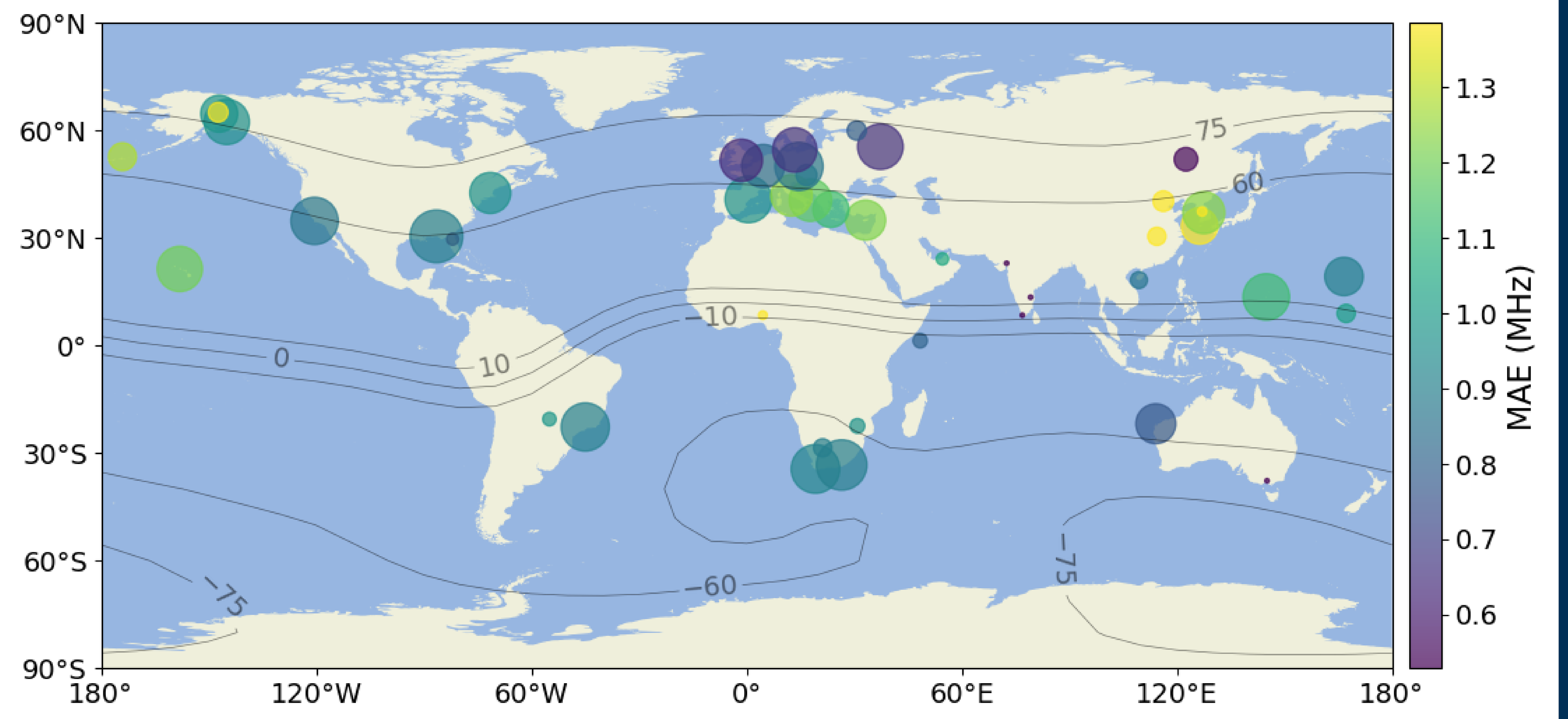
For the models to do better on rare cases (e.g, high intensity Es), the loss function is weighted to improve performance in those areas.





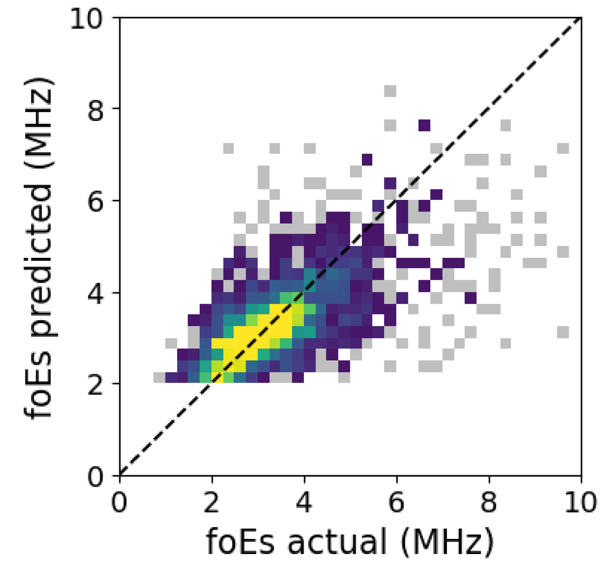
Model Performance

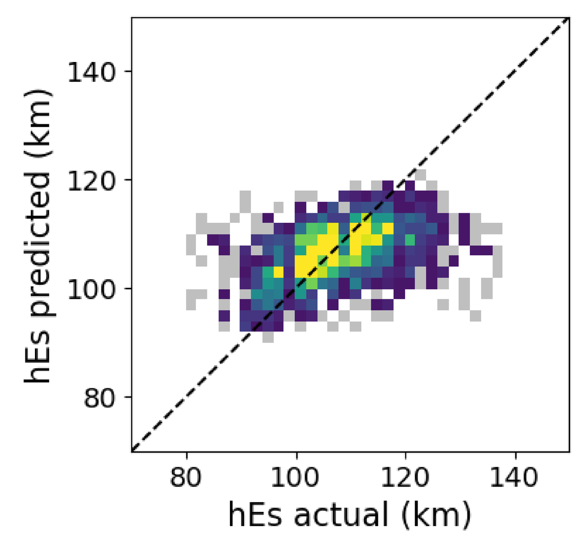
The map shows the performance of the full model (i.e., all models are chained together), while the tables and heatmaps show individual model performance. Good performance is achieved, even when compared to other models using the same dataset.



Model	*Accuracy*	*Recall*	*Precision*	*F1-score*
Binary Classification				
CNN – unweighted	**0.75**	0.69	**0.69**	0.69
CNN – weighted	0.74	**0.76**	0.65	**0.70**

Model	*RMSE*	*MAE*	*Bias*	R^2	r
hEs					
TEC	12.13	8.91	-4.87	-0.85	0.19
$S_{4,max}$	12.03	8.66	-4.16	-0.87	0.22
CNN	**7.89**	**5.81**	**-0.70**	**0.20**	**0.46**
foEs					
TEC	1.45	1.07	-0.39	-0.32	0.41
$S_{4,max}$	1.36	1.02	0.47	-0.19	0.49
CNN	**0.95**	**0.63**	**-0.07**	**0.43**	**0.66**





Summary

- CNN models show good results in predicting whether sporadic E is present along with characterizing its height and intensity using radio occultation data
- The classification and regression tasks can be chained together to provided an end-to-end Es assessment

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