DATA-07

A Deep Neural Network Model through Automatic Optimization for Ionospheric Electron Density

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Objective

- The ionospheric electron densities depend on various parameters.
- The artificial neural networks (ANNs) shows limited performance in the fitting and prediction task.
- The Automated Machine Learning (AutoML) guides the deep neural networks (DNNs), which leads to better outcomes.
- The electron density diurnal patterns show the potential of catching up limited dynamic features in a time-resolved way.

Abstract

- We relate the electron density (N_e) with parameters: year, month, day of year (doy), $F_{10.7}$, ap3, magnetic local time (MLT).
- The database comes from Incoherent Scatter Radar (ISR), a total 15 year of data is selected to train the model.
- The automated machine learning guides the optimization on the hyperparameters of DNN, which is convenient and cost-saving.
- The comparison between ANN and DNN shows the improvement is up to 25% on the fitting and 16% to the prediction.

Method - DNN

- The neural networks are the tools used in this work, especially ANN and DNN.
- Neural networks are suitable for regression.
- The general DNN structure is demonstrated as in Figure 1. ANN would be of only one hidden layer.

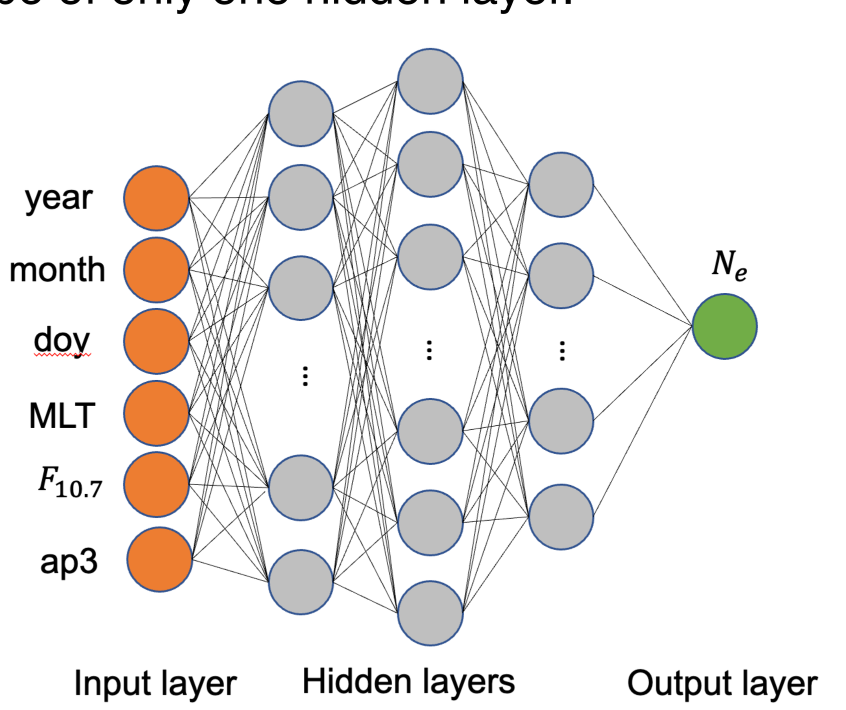

Figure 1. DNN architecture.

Experiments and Results

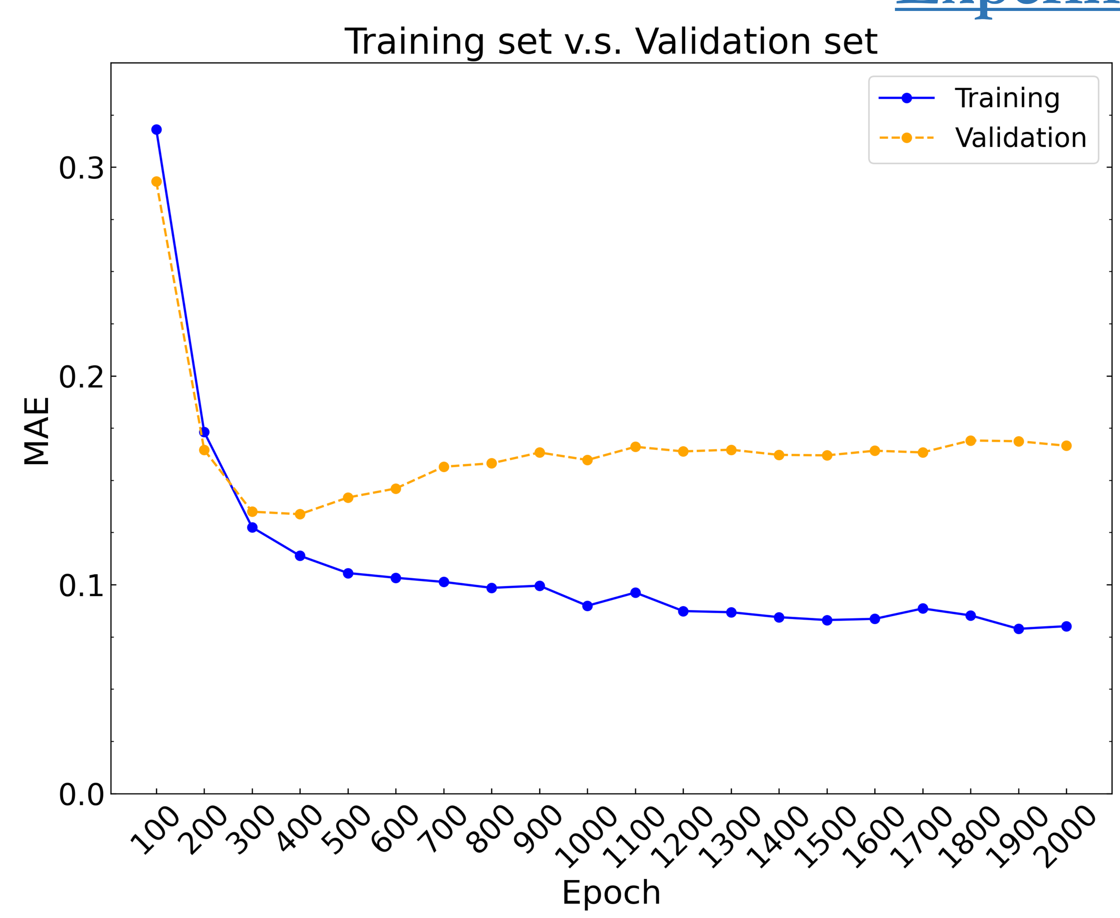

Figure 3. Loss curves between training set and validation set of DNN.

- Overfitting remains an issue for DNN.
- The dip epoch, where the dip of the validation loss curve is, is referred to be the model of interest for analysis.

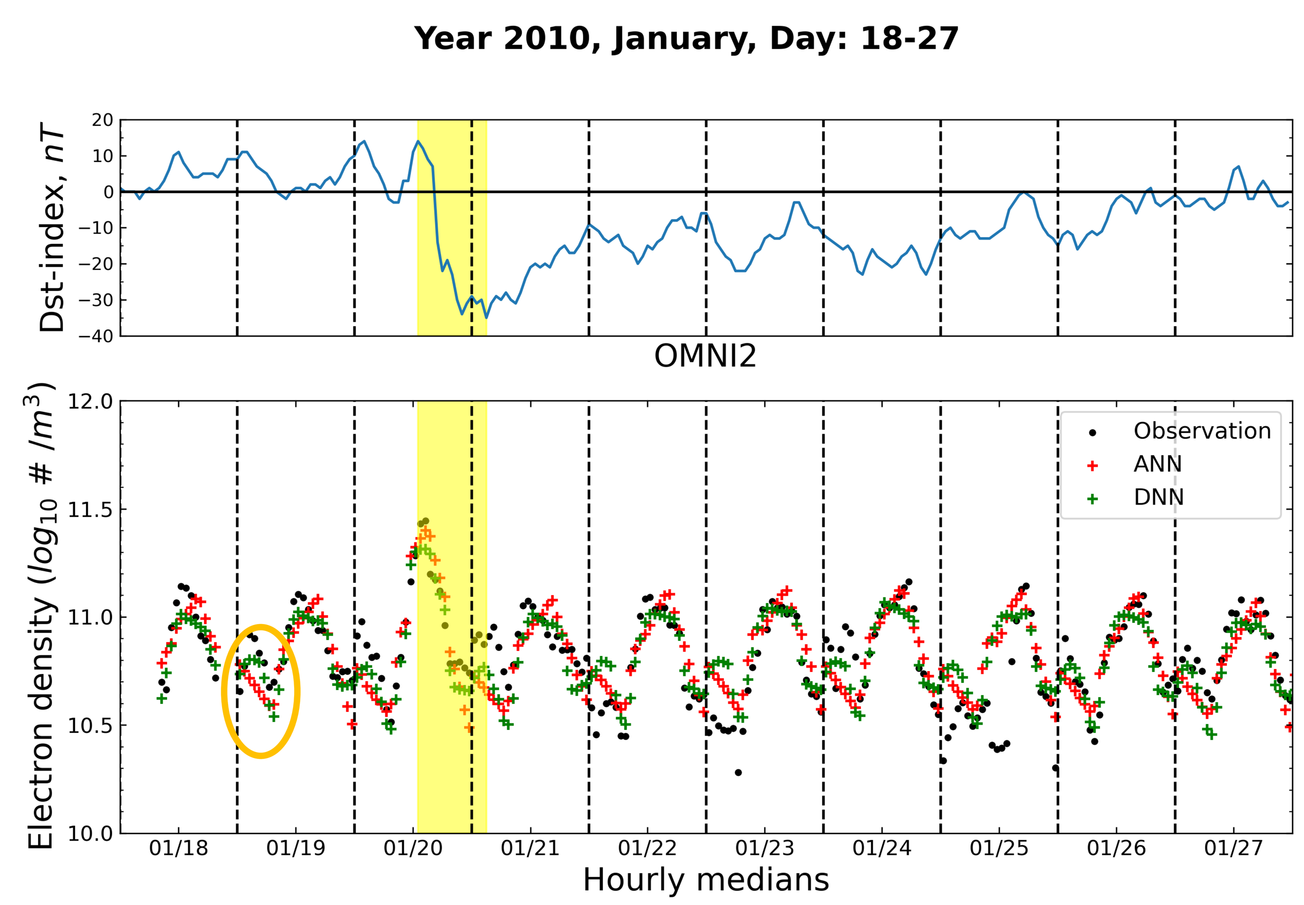

*Figure 5. Dst index and N_e observations v.s. **fittings** from Jan 18th to Jan 27th, 2010.*

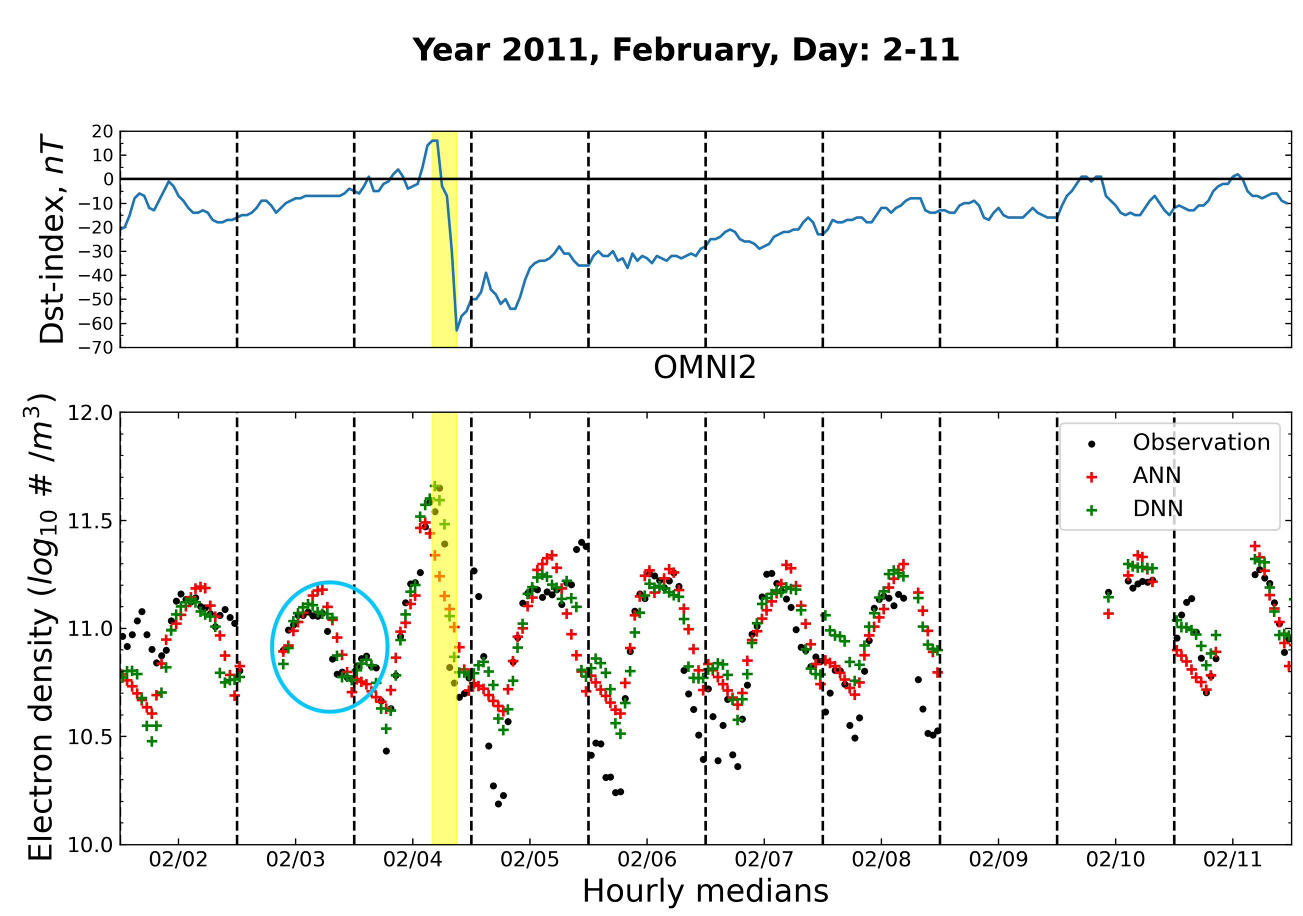

*Figure 6. Dst index and N_e observations v.s. **predictions** from Feb 2nd to Feb 11th, 2011.*

Table 1. Metric results between ANN and DNN.

	Fitting		Prediction	
	ANN	DNN	ANN	DNN
MAE	0.1513	0.1138	0.159	0.1338
RMSE	0.2066	0.1599	0.2073	0.1795
RE (%)	1.3589	1.0214	1.4158	1.1913

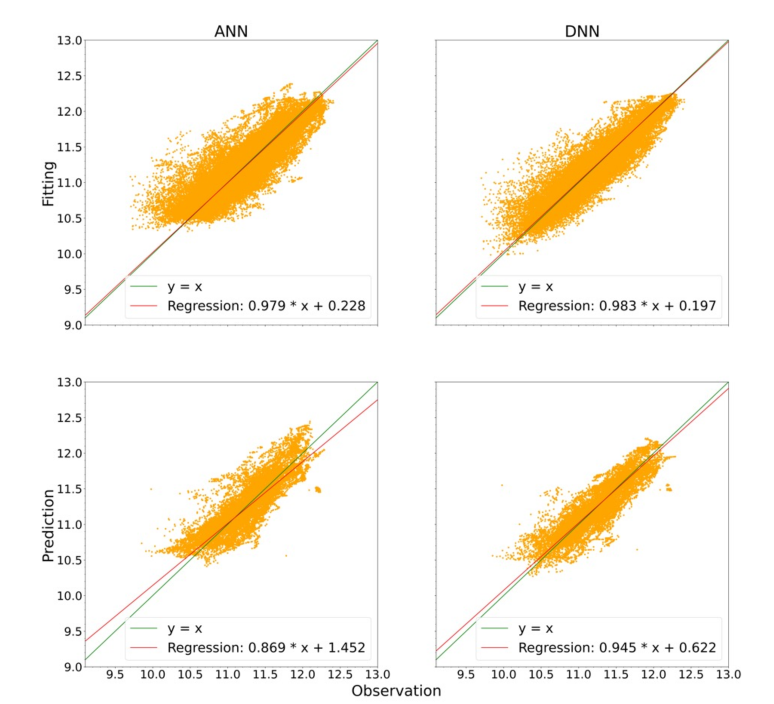

Figure 4. Observations v.s. fittings/predictions.

Quantitatively:

- the improvement of DNN over ANN is up to 24.8% on the fittings, while up to 15.9% to the predictions.
- The prediction results lead to slightly larger errors compared with the fitting results.

Qualitatively:

- The regression lines of fittings are closer to the reference line ($y = x$) than that of predictions.
- DNN leads to better slope and offset of the regression line.

Two case studies at geomagnetic storm events (for fitting and prediction, respectively).

- The disturbance storm time (Dst) index is drawn at the top row to refer to the storm onset and intensity.
- The yellow ribbon regions indicate the dive of Dst index.

A moderate storm is observed on January 20th, 2010.

- Zigzag-shaped diurnal patterns are pronouncing.
- In the orange circled region, the pre-dawn N_e enhancement is well reconstructed by DNN than ANN.

A super storm is observed on Feb 4th, 2011.

- The N_e behaves differently as the Dst dives.
- The discontinuous N_e is hard to predict by both models.
- A "basin" is shown in DNN predictions, which disclose more detailed structures.

Method - AutoML

The AutoML logic is plotted below in Figure 2.

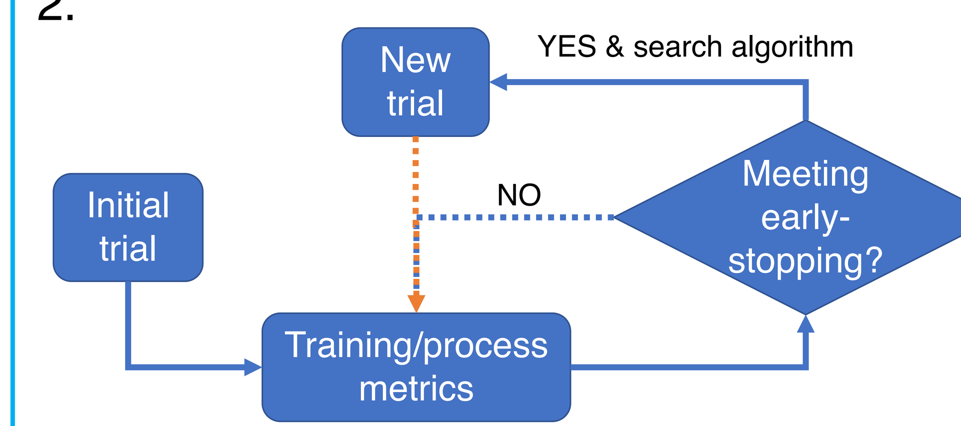

Figure 2. AutoML flowchart.

- A trial is the individual configuration of an intact neural network.
- The processing of metrics would include calculating, comparing, and recording the objective parameter which is the criterion for the neural network optimization.
- Search algorithm guides to the next trial.

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Conclusion

- The ionospheric electron density is related with other parameters, time stamp, solar activity, magnetic activity, etc. Those parameters serve as the inputs of the neural network.
- Both the neural networks (ANN and DNN) perform decently in fitting work, while the prediction work is challenging and the ANN suffers from a depression in the predictions.
- The automated machine learning lowers the cost in optimizing the model with better performance.
- The DNN outperforms the ANN. More detailed electron density structures are present in the diurnal scale.
- The DNN shows such potential in providing the consistent tool in studying the climatological features in resolved temporal resolution.