Modeling ionograms with Deep Neural Networks: Contrasting models

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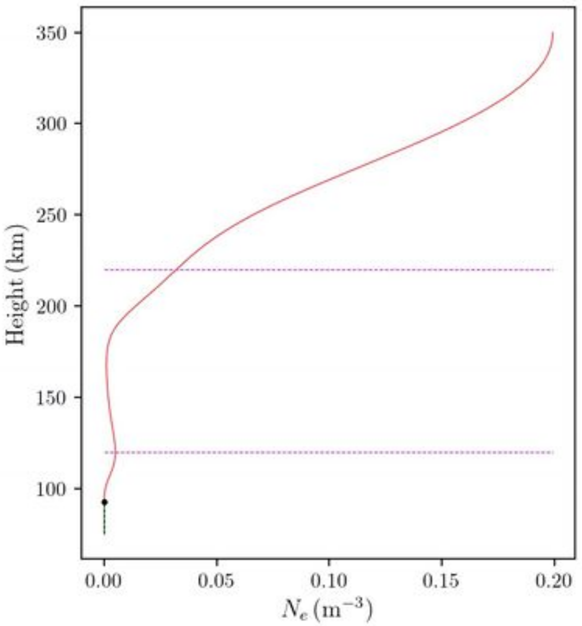
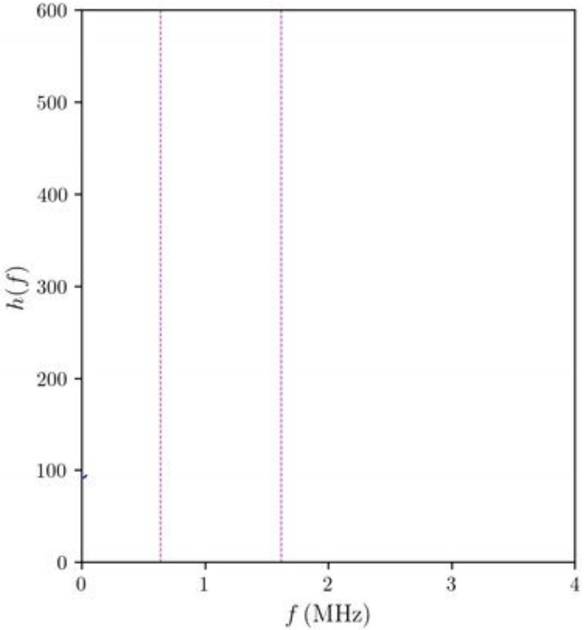
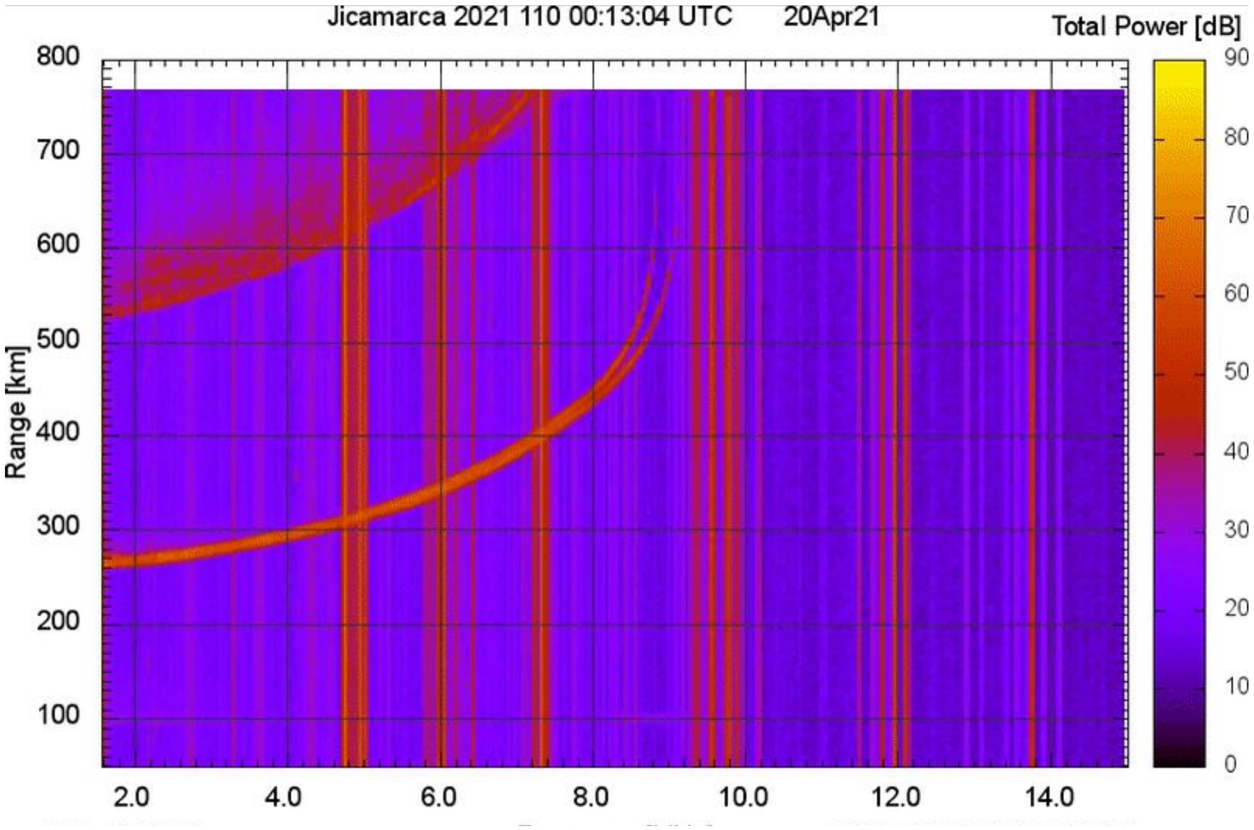
Scientific problem





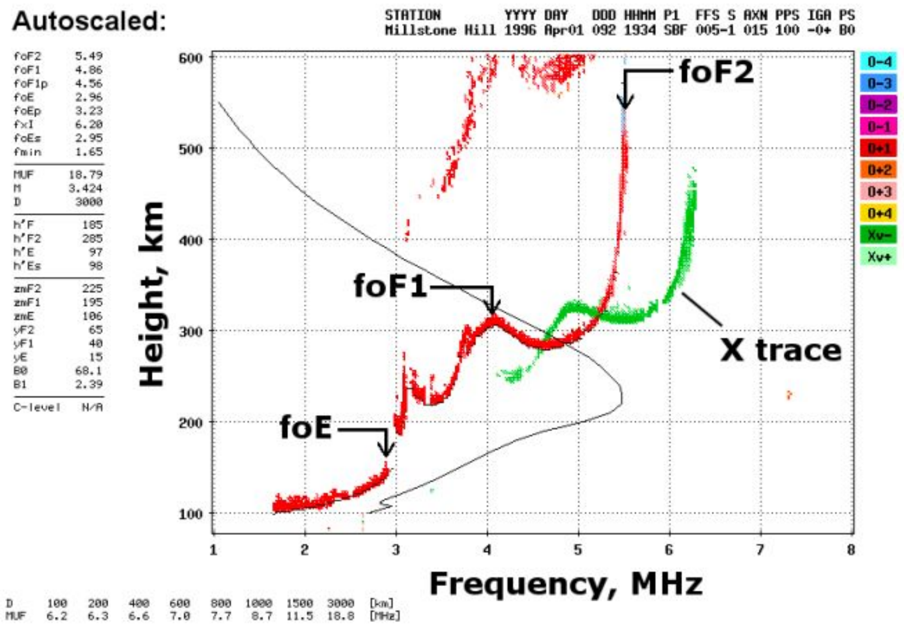
$$h(f) = \int_0^{z_r} \frac{dz}{n(z)} = \int_0^{z_r} \frac{dz}{\sqrt{1 - \frac{fp(z)^2}{f2}}}$$

What is h(f)?

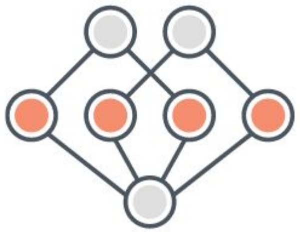


DPS4 digisonde give **ionograms** data every 15 minutes

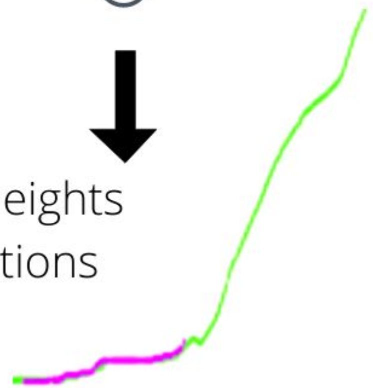
Why do we need to estimate foF2?



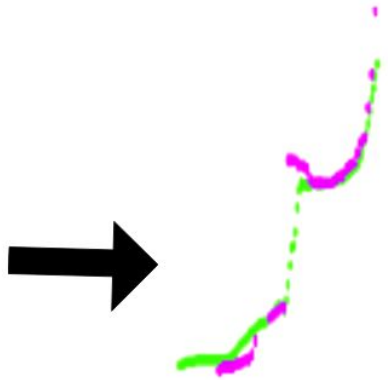
Frequencies + inputs



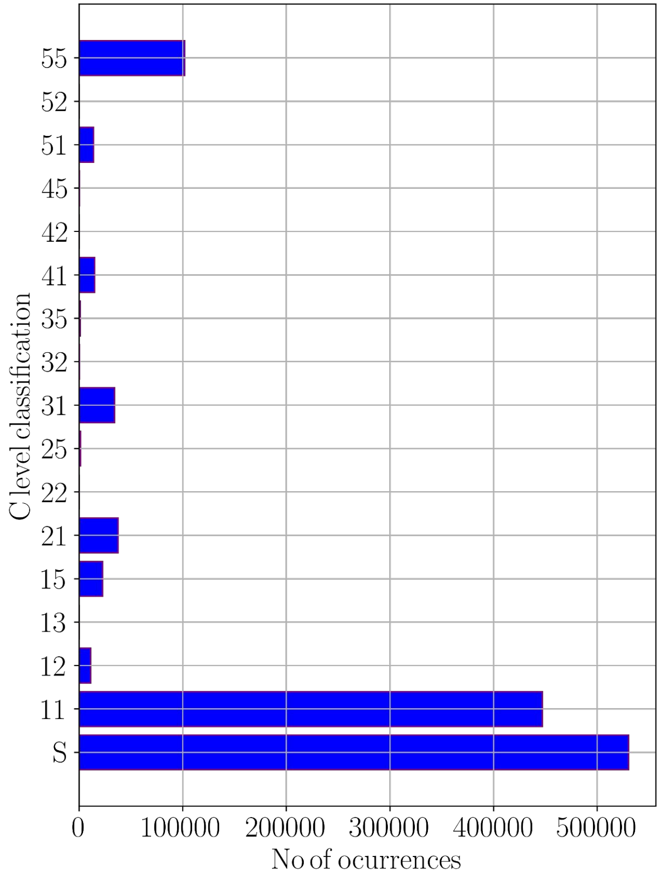
Virtual heights predictions

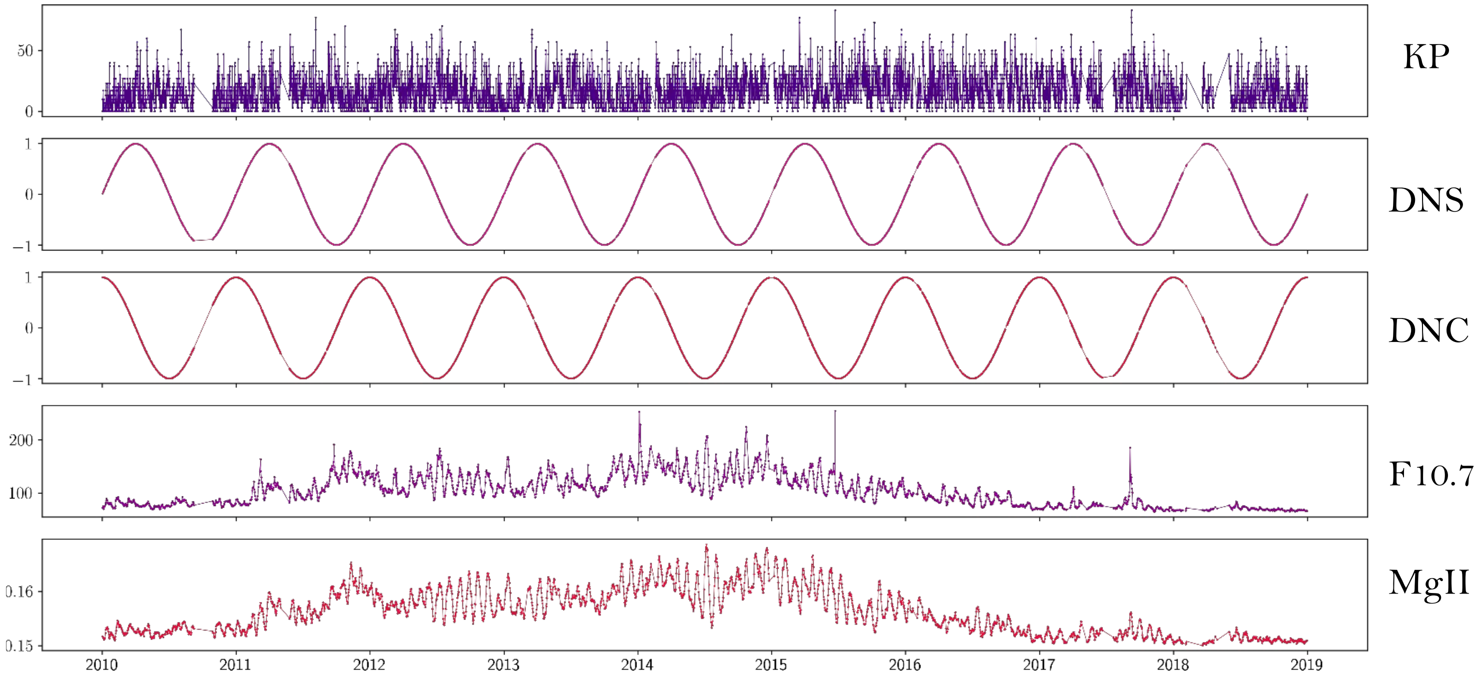


Ionogram:
Virtual heights
predictions limited by foF2



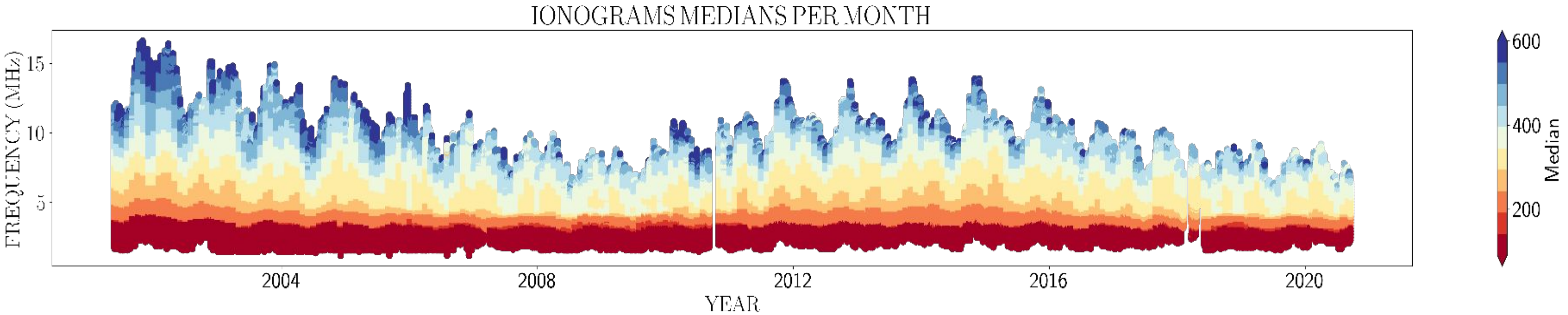
Datasets

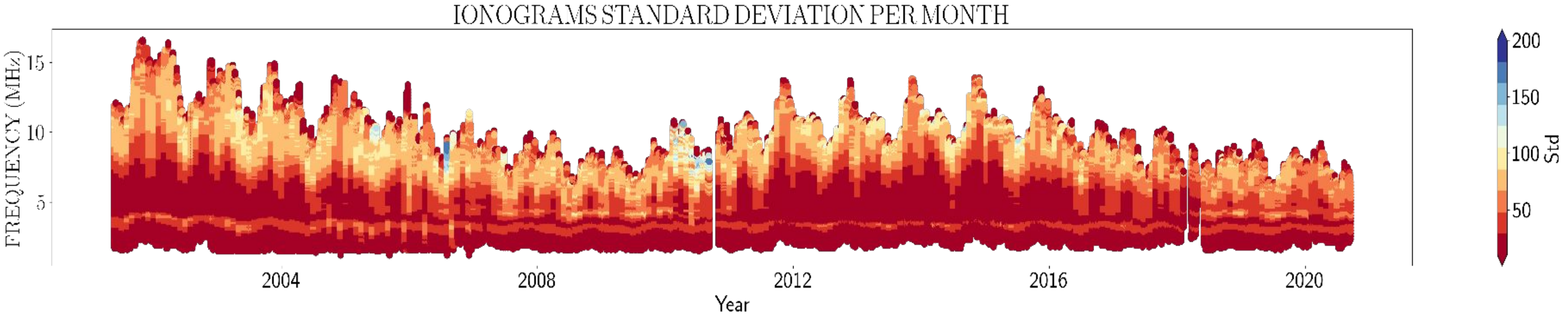




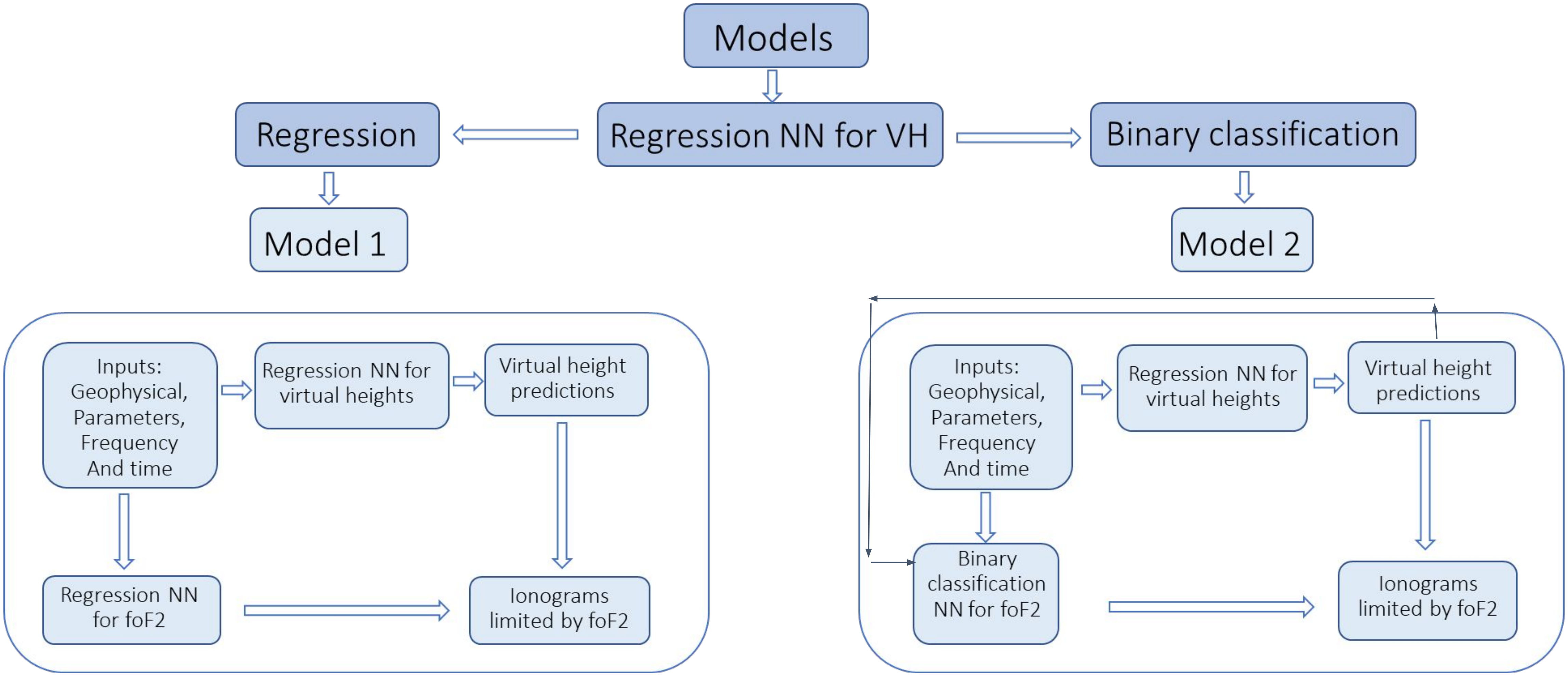
The c-level flag indicates and qualifies some ARTIST scaled results [1]. Day of year values were converted into 2 quadrature components to avoid discontinuities as proposed in [2]. Mg II is a good solar proxy for foF2[3]

Datasets: ionograms



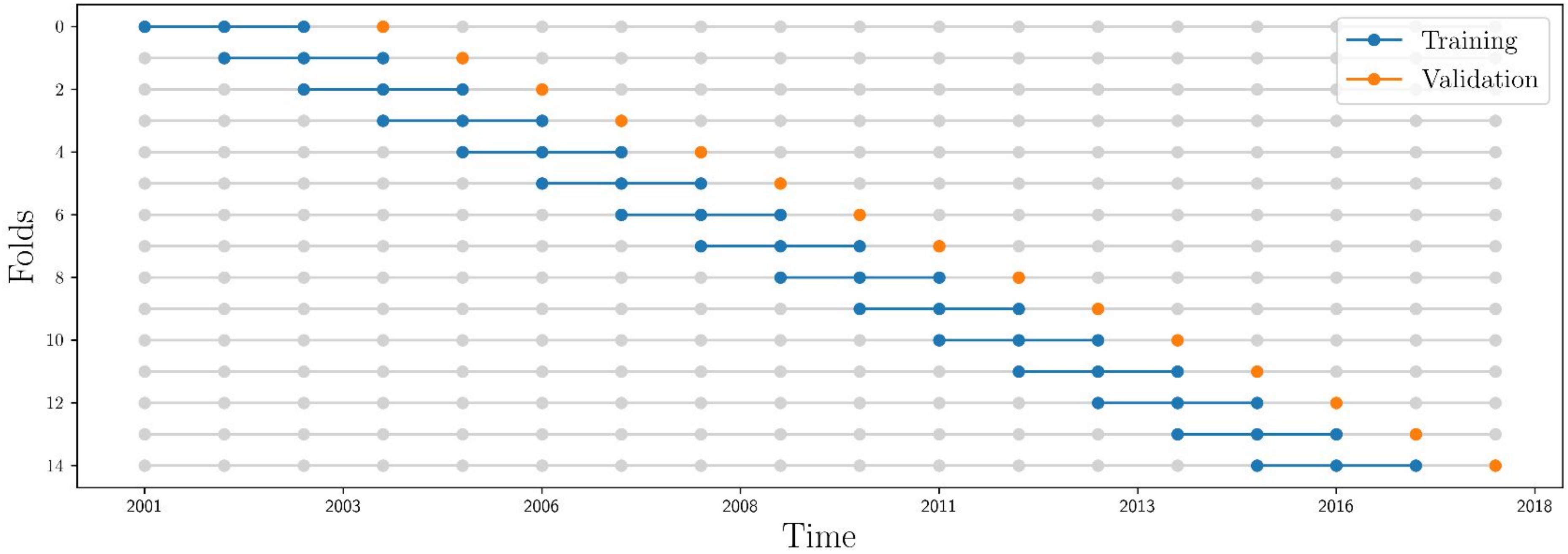


Models



Models
Regression
Regression NN for VH
Binary classification
Model 1
Model 2
Inputs: Geophysical, Parameters, Frequency And time
Regression NN for virtual heights
Virtual height predictions
Regression NN for foF2
Ionograms limited by foF2
Inputs: Geophysical, Parameters, Frequency And time
Regression NN for virtual heights
Virtual height predictions
Binary classification NN for foF2
Ionograms limited by foF2

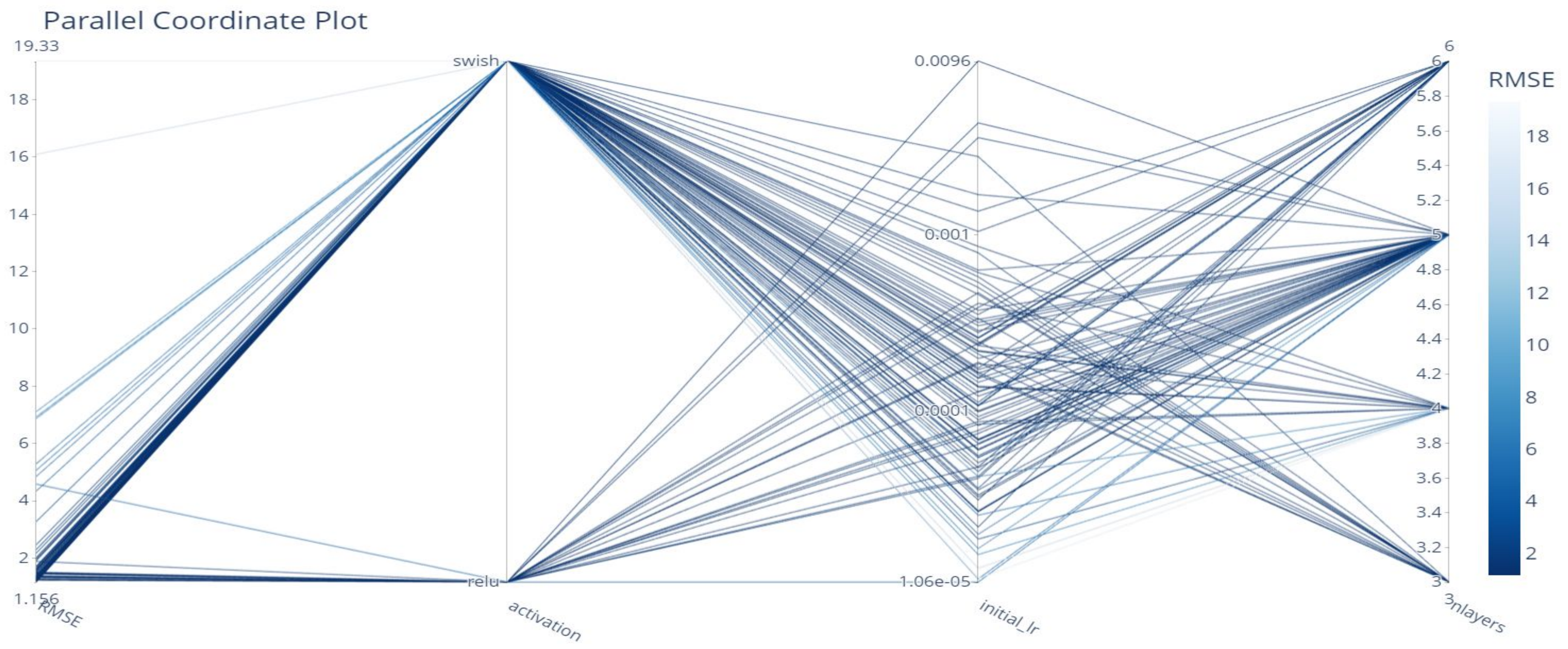
Hyperparameter optimization: Folds



- Sliding window

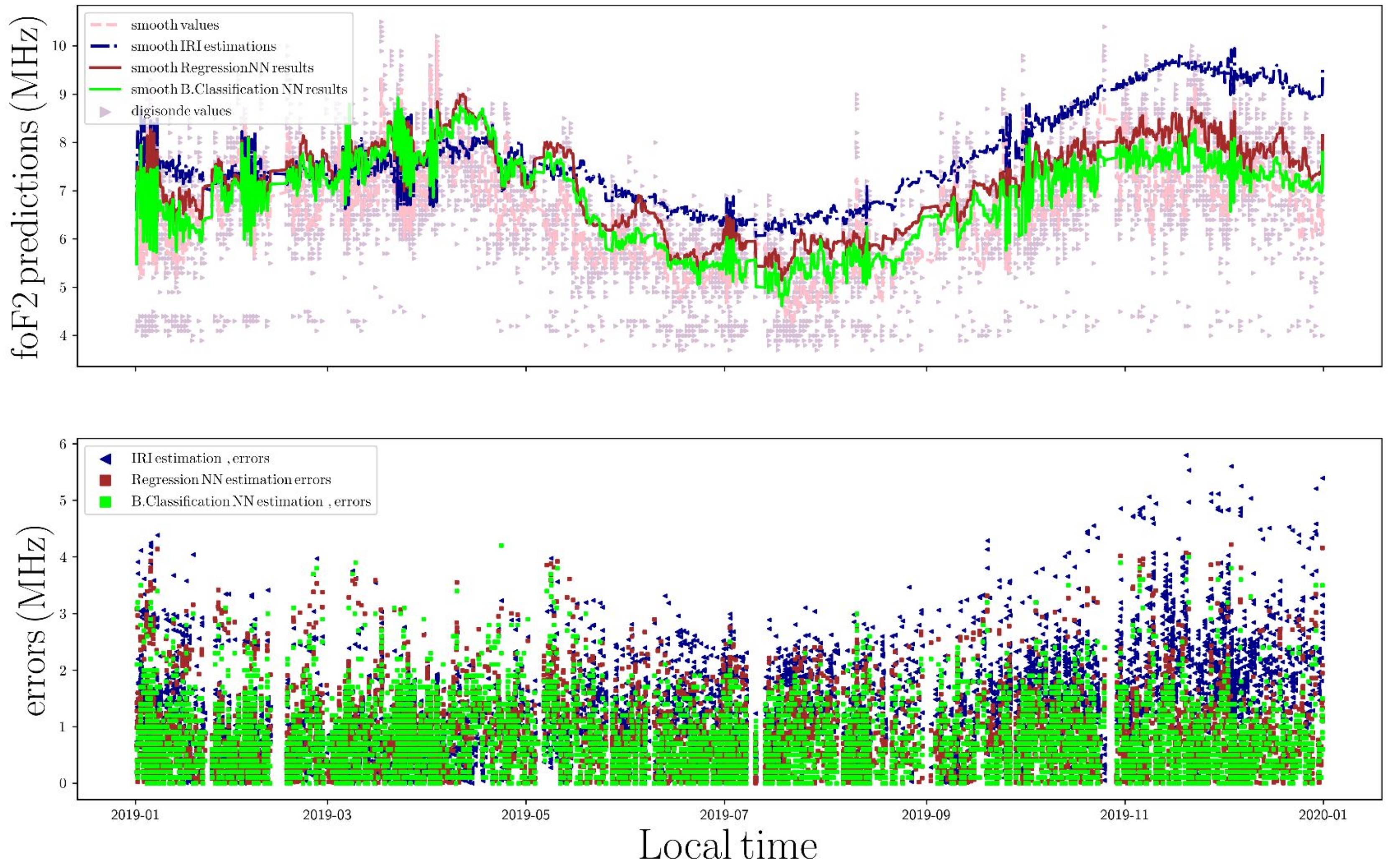
18 years of data was used to train and validate our models, the year 2019 was used as testing data

Hyperparameter optimization: Optuna

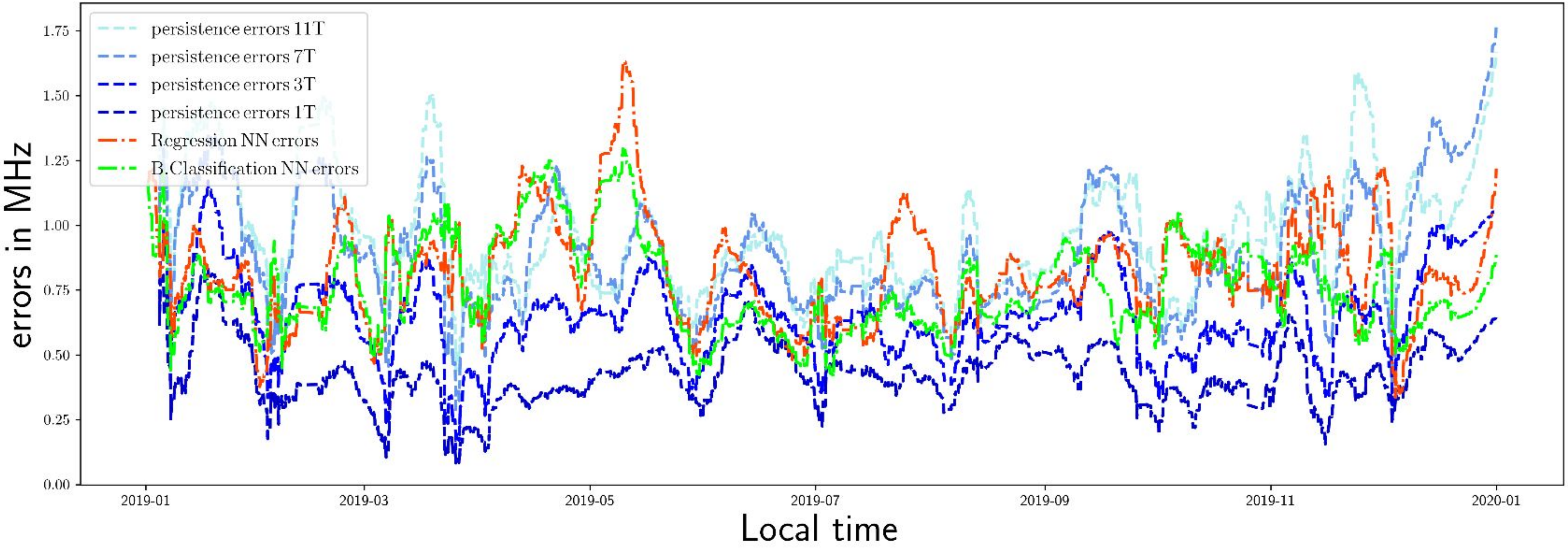


intervals for parameters where chosen based on previous jobs[5]

foF2 comparisons and results

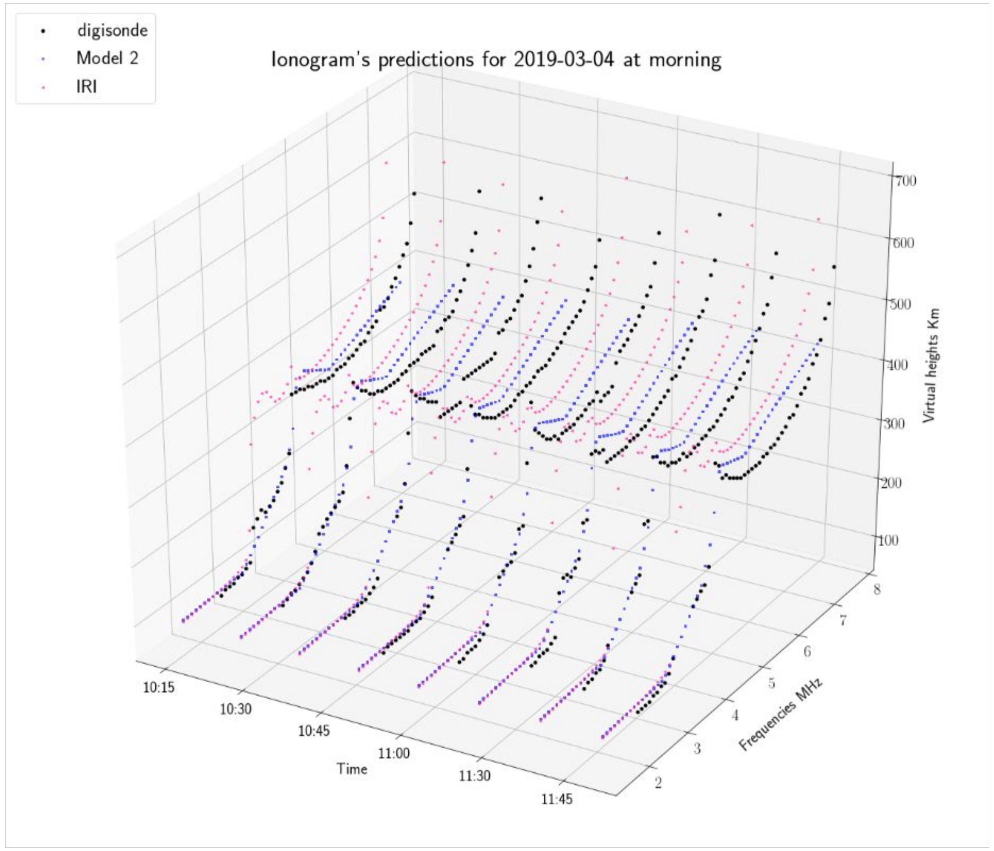


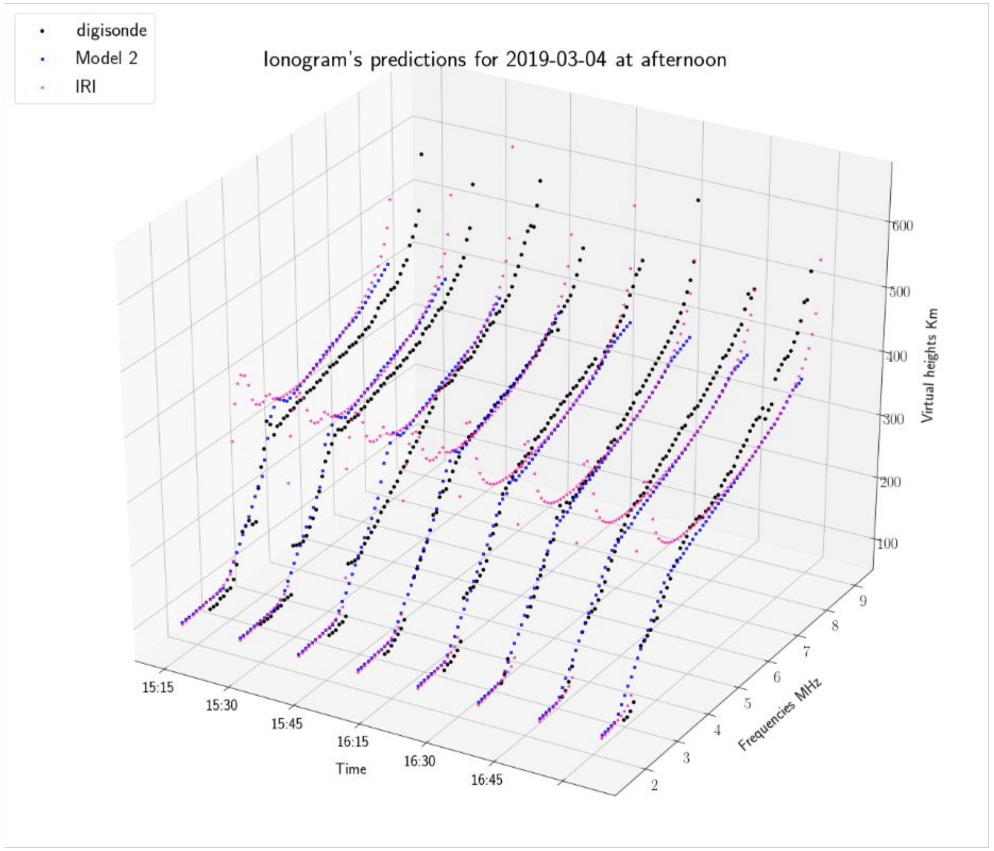
foF2 comparisons and results



The persistence model uses the value at the previous time step (t-1) to predict the expected outcome

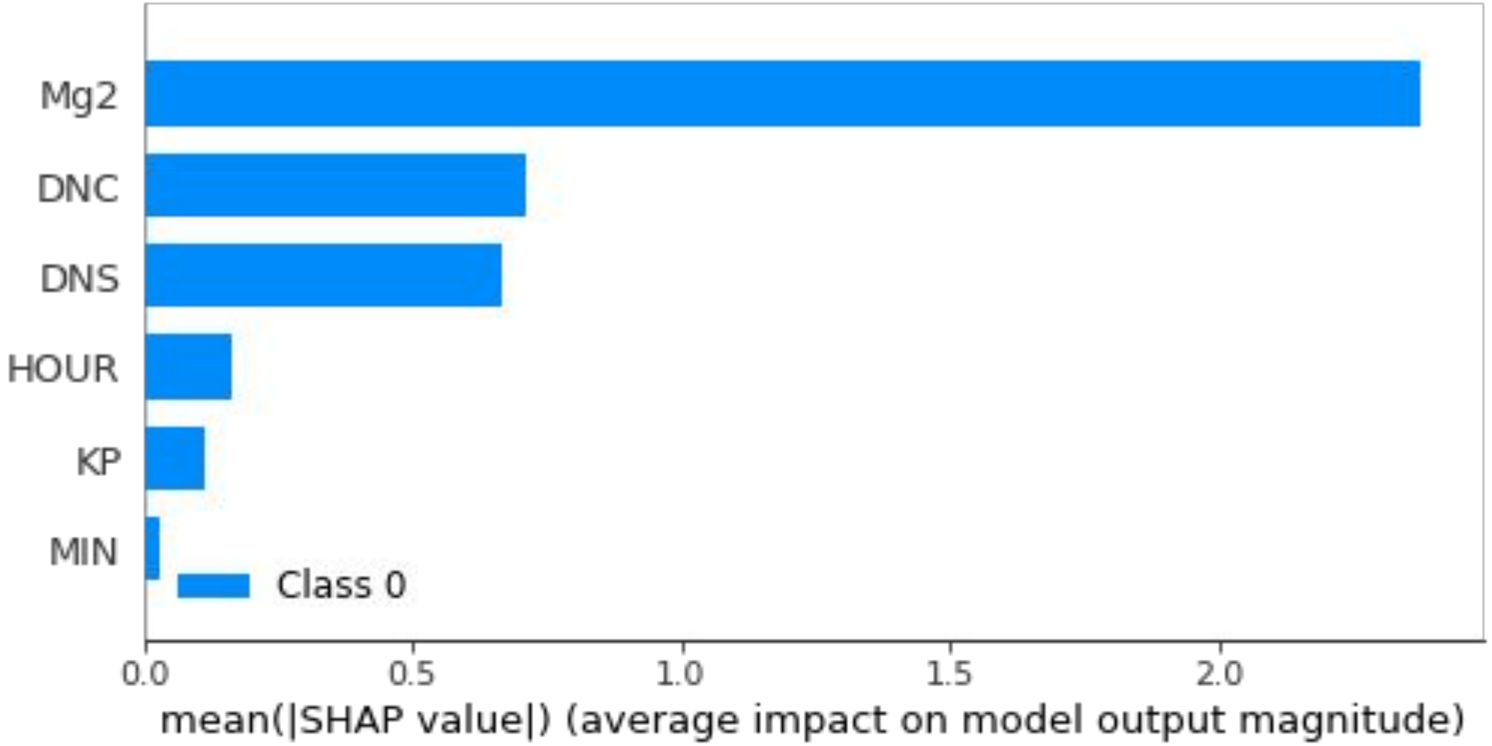
Ionograms comparisons and results



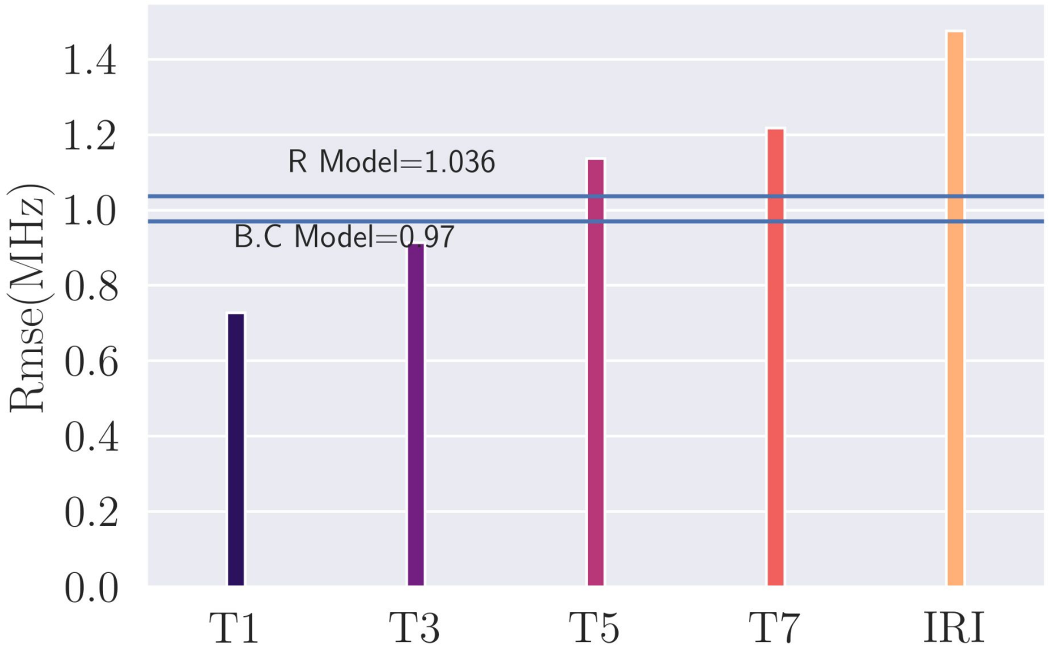


- Ionograms predictions of model2

Parameter inputs importance

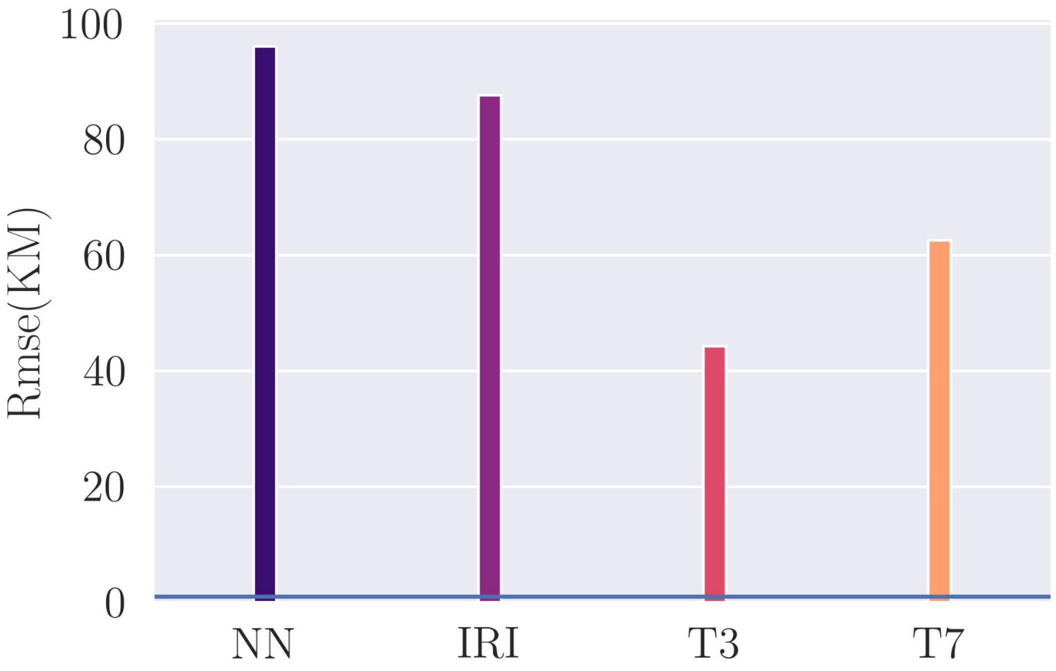


Comparisons between models



Persistences and IRI

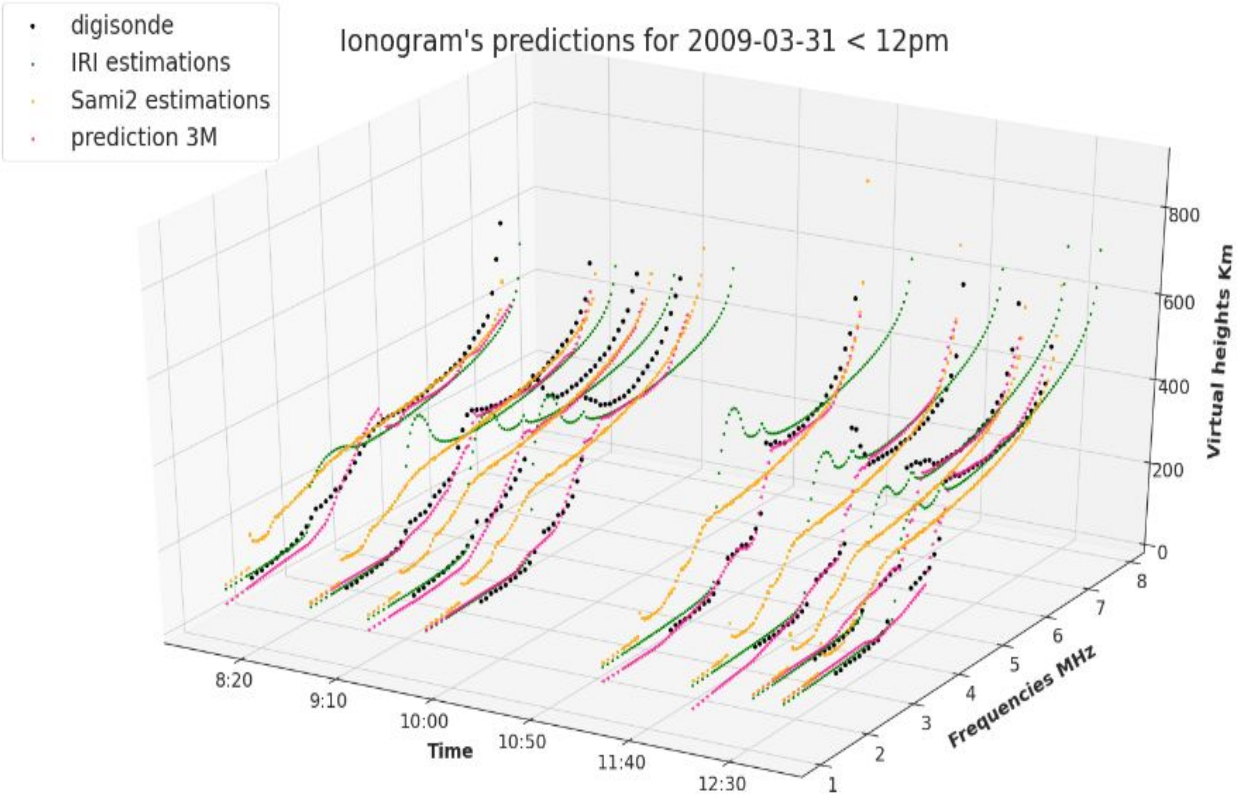
RMSE for foF2



Persistences and IRI

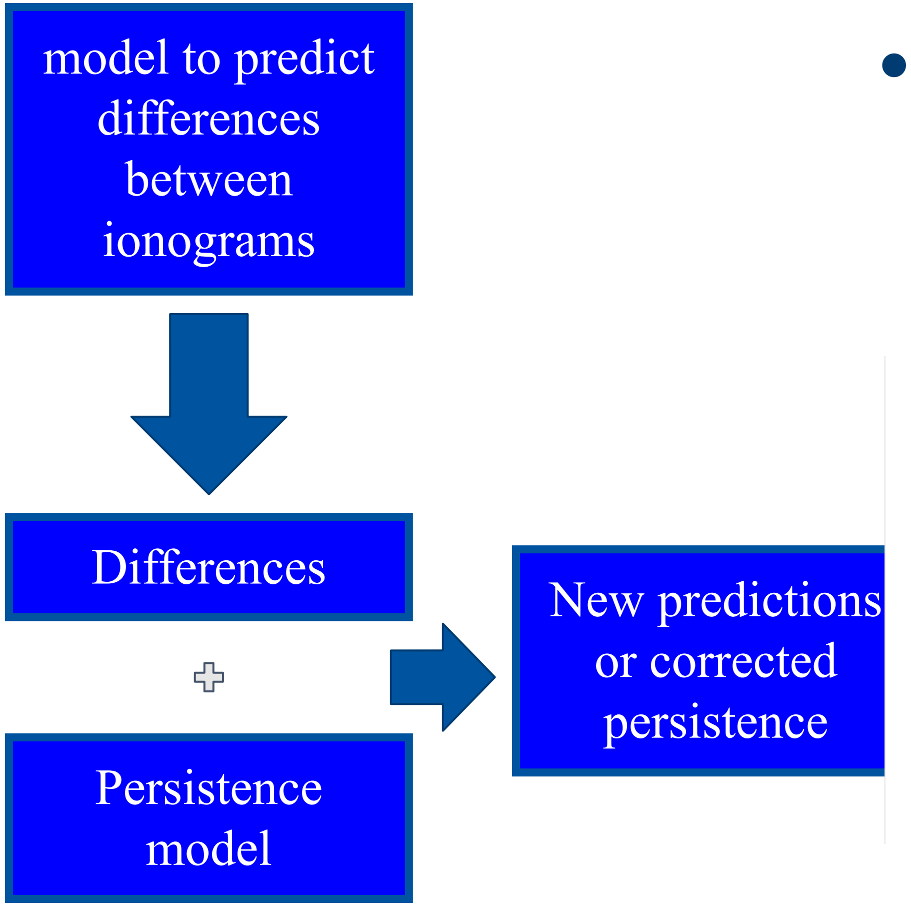
RMSE for ionograms

Comparisons with previous model

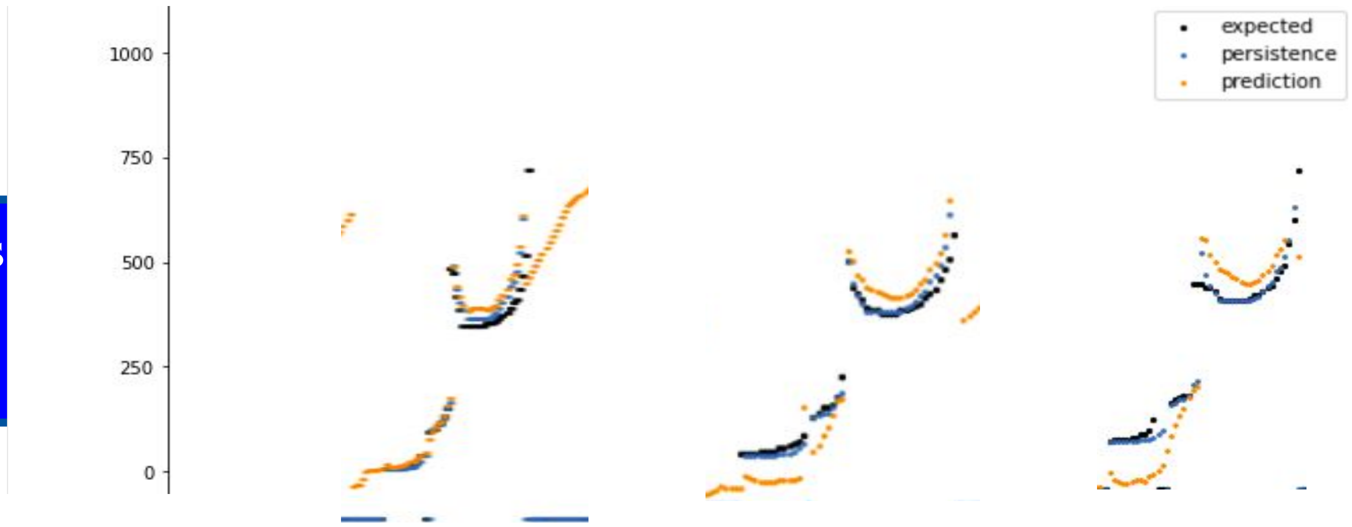


Evaluation of neural network models to estimate foF2 (RMSE-MHz)				
Metrics	Model 2 (1 month of data)	Model 2 (3 months of data)	IRI ESTIMATIONS	SAMI2 ESTIMATIONS
Solstice of a Solar Minimum (December 2009)	0.44	0.47	1.12	0.59
Equinox of a solar minimum (March 2009)	0.58	0.51	1	0.75
Solstice of a solar maximum (June 2014)	0.62	0.82	0.67	1.47
Equinox of a solar maximum (March 2013)	1.81	1.53	1.25	0.70

Nowcasting approach



- This nowcasting approach predicts ionograms for the next one or two hours. Here are some preliminary results:



Conclusions and future work

- By using not only frequencies that are foF2 but also frequencies that are not and virtual heights to estimate foF2, we can observe that this approach is slightly better than using a regression neural network for foF2 for the testing year.

- After making tests on small datasets, we can observe through the good estimations that using deep learning or Machine learning approaches with non-complex models can have potential applications to make ionosonde parameters forecasting using ionosondes with few data or recently installed ionosondes.

- We will continue exploring the nowcasting approach.

- Future work will be oriented toward electron densities forecasting.

References

1. https://www.digisonde.com/pdf/Digisonde4DManual_LDI-web.pdf
2. Poole, A. W. V., & Mckinnell, L. A. (2000). On the predictability of foF2 using neural networks. Radio Science, 35(1), 225–234. https://doi.org/10.1029/1999RS900105.
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4. Optuna: A Next-generation Hyperparameter Optimization Framework. Takuya, Akiba, y otros. 2019. 2019. Proceedings of the 25th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining. DOI: 10.1145/3292500.3330701.
5. **L.A. McKinnell,** Equatorial predictions from a new neural network based global foF2 model 2009(feed-forward)

Thank you