Machine learning model of the plasmasphere to forecast satellite charging caused by solar storms.

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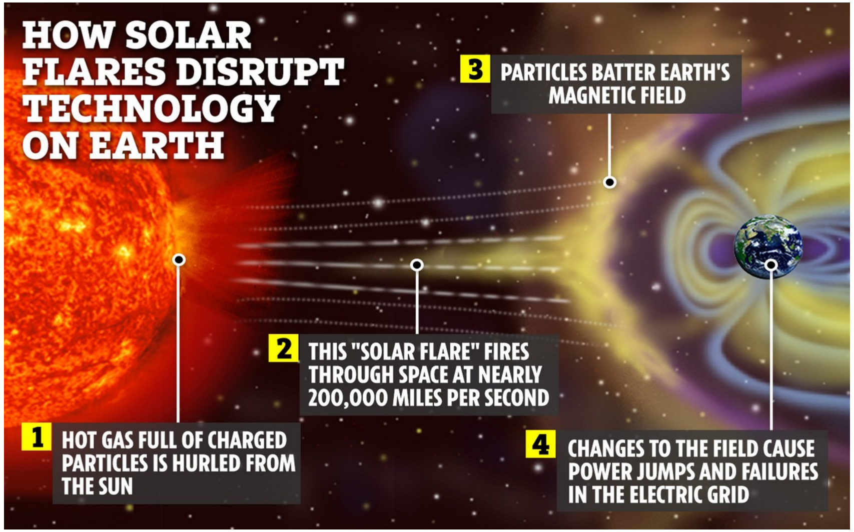
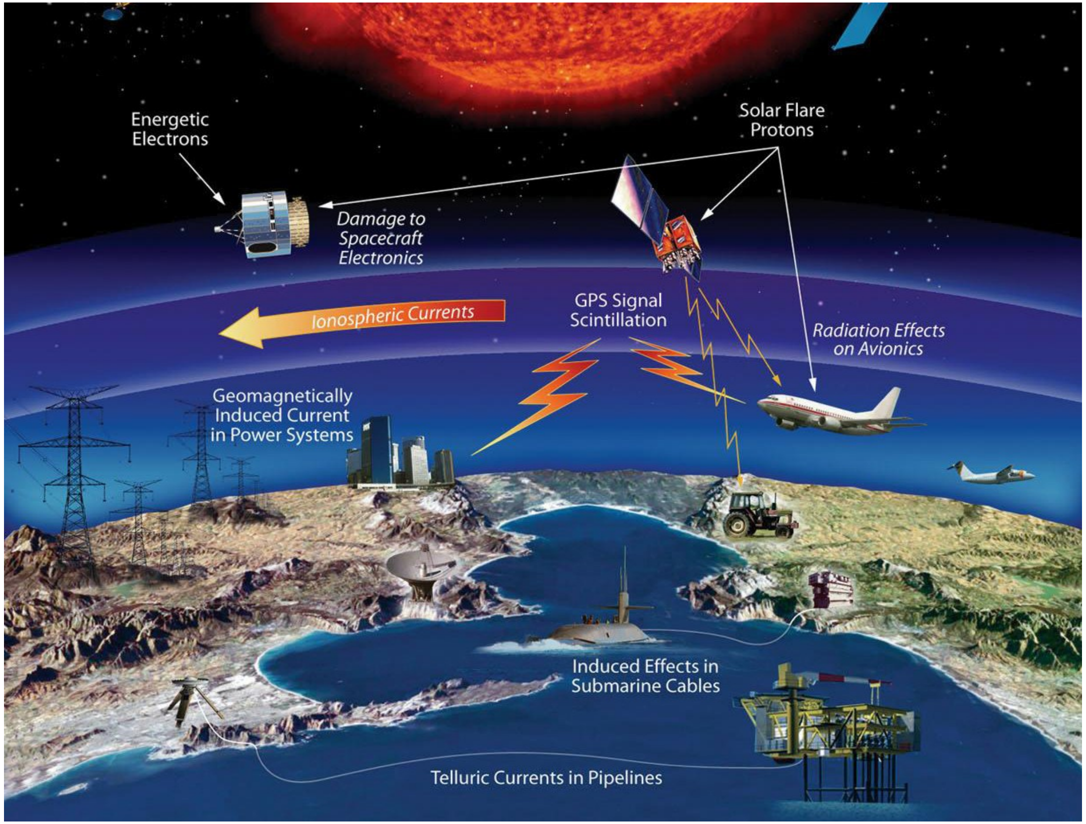
Solar storms can cause serious damages in space and on Earth.

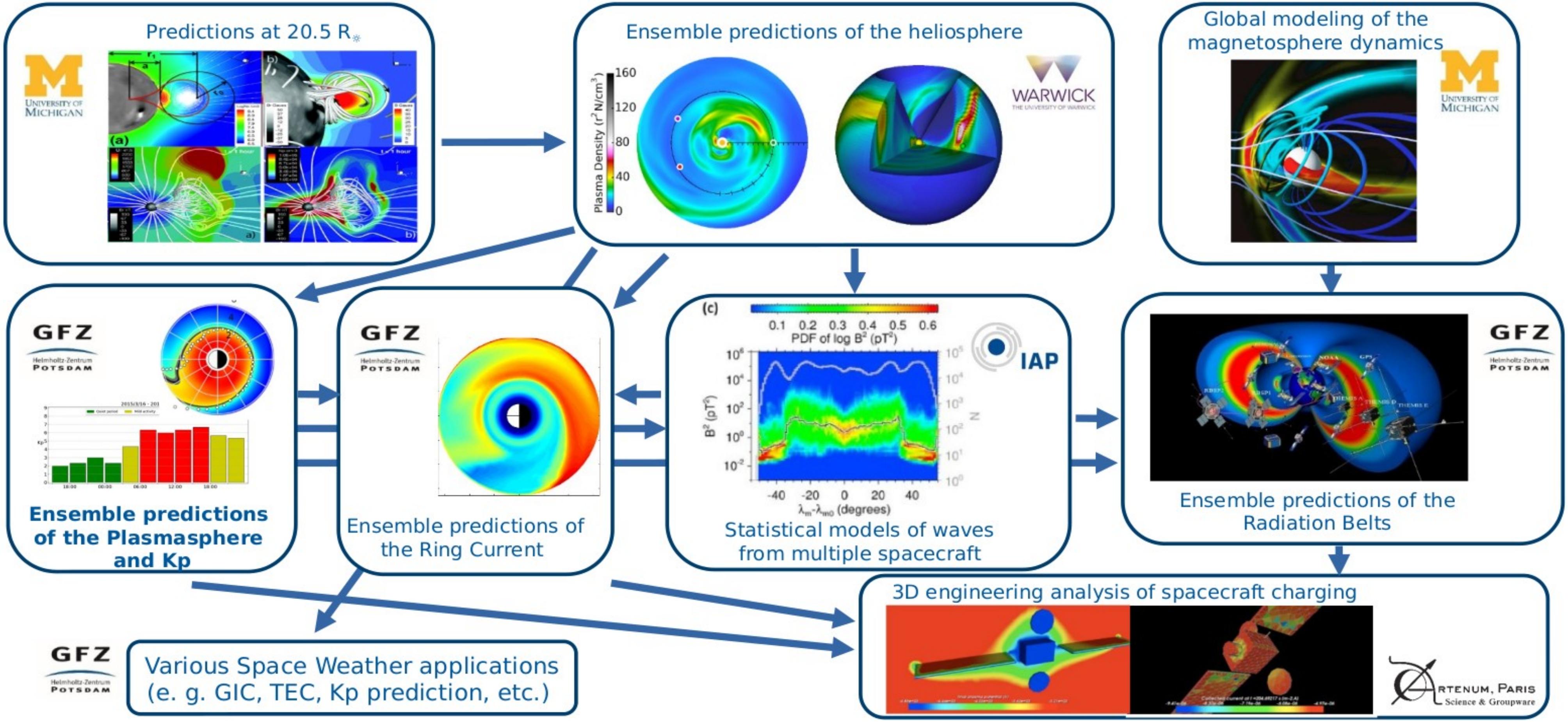


Credits: The Sun

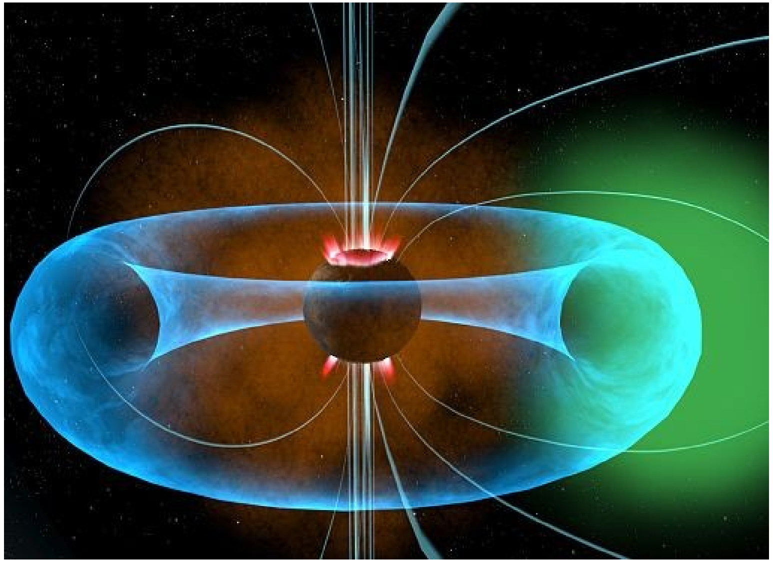


Credits: Nasa

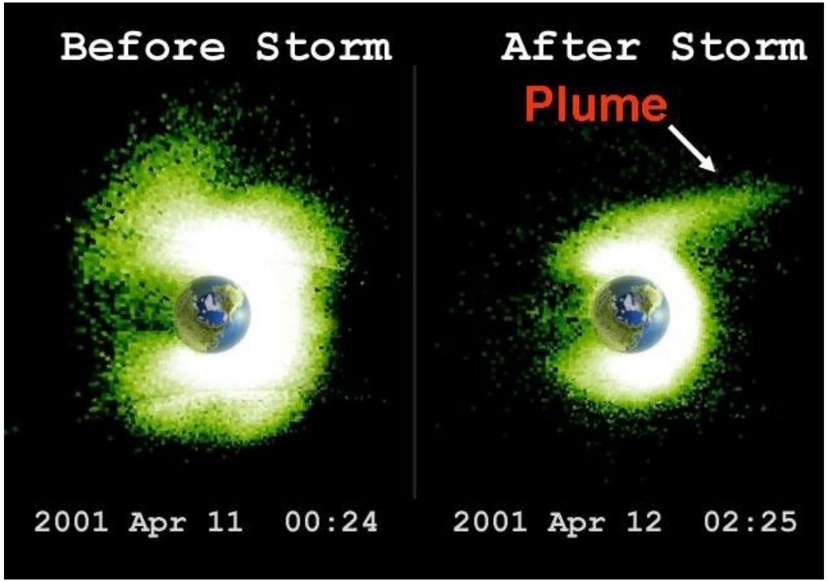
The PAGER project aims to provide forecast of satellite charging, part of it is the modeling of the plasmasphere.



The plasmasphere is a toroidal region of cold plasma around the Earth.



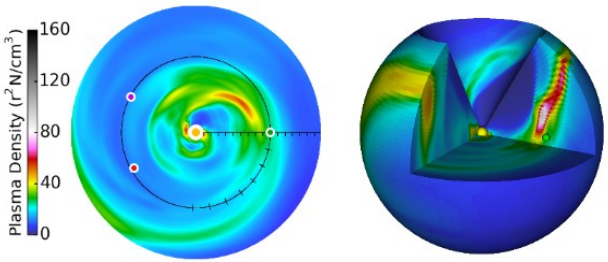
Credits: NASA



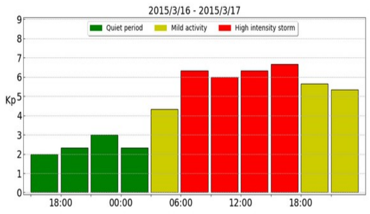
Credits: J. Goldstein et al 2007

In PAGER, forecasted solar wind and Kp are used as inputs to the plasmasphere model .

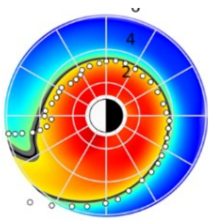
Prediction of the solar wind at L1 point.



Prediction of Kp index.



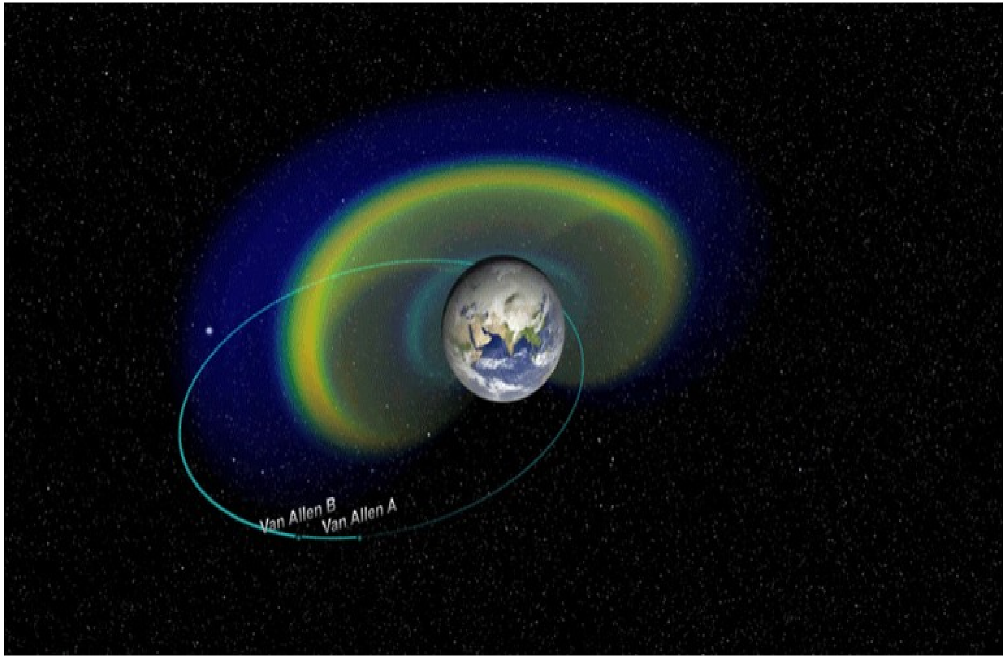
Prediction of the plasma density in the plasmaphere



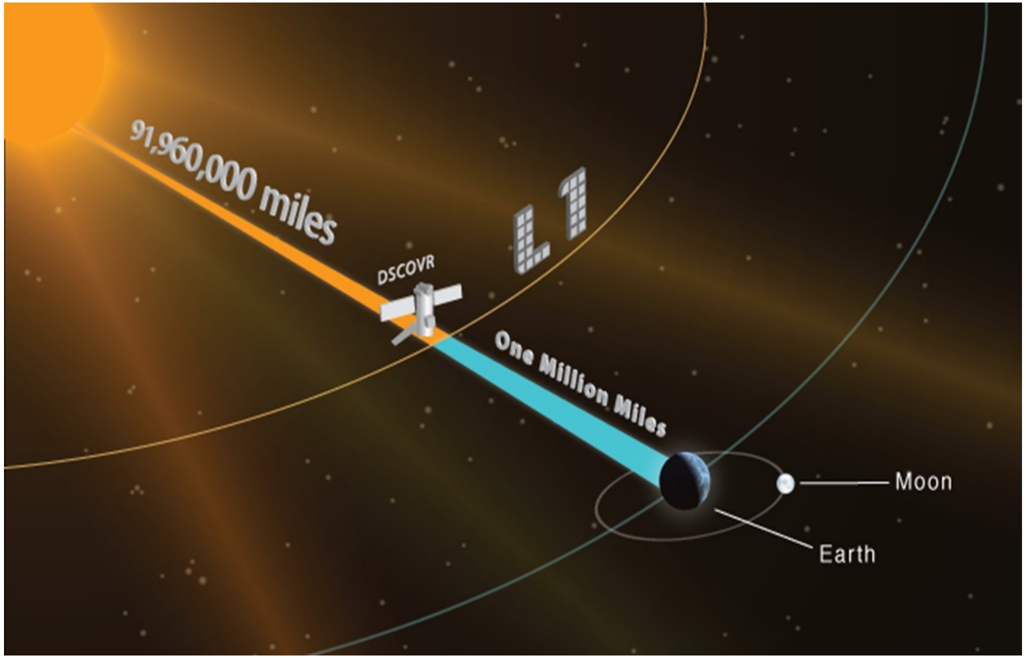
To develop the model we use in-situ density measurements and measured solar wind at L1 and Kp.

Van Allen Probes: density measurements between $6 \cdot 10^2$ and $3 \cdot 10^4$ Km, 1 min resolution ~4 years time span, 9 hour orbit.

Discovery spacecrafts give solar wind features at L1 with 1 min resolution, from OMNIWeb.



Credits: NASA's Goddard Space Flight Center



Credits: Nasa

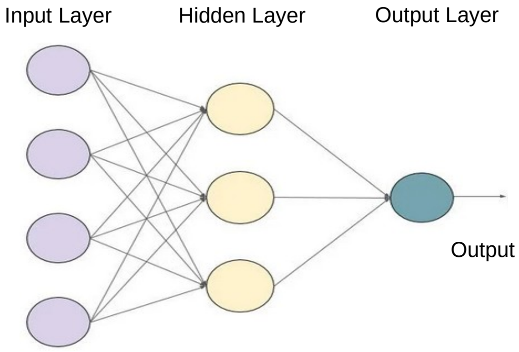
Using time aggregates of the features and feedforward network constitutes an effective approach.

PINE model, Zhelavskaya et al. 2017

Input

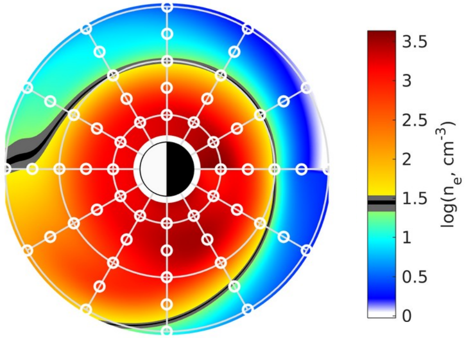
- 48-hour time history of geomagnetic indices Kp, AE, SYM-H, and F10.7
- Location

Feedforward neural network



Fully-connected Sequential (no cycles) neural network.

Output



The model outputs and reproduces the plasma density in the equatorial plane of the plasmasphere.

We choose $V_{sw} \cdot B_s$ and ρ_p as solar wind features, and we consider history up to three days in the past.

Kp index, $v_{sw} \cdot B_s$ and ρ_p are important for the plasmapause dynamics (He et al. 2017)

Inclusion of proper time history is crucial

$v_{sw} \cdot B_s$, ρ_p

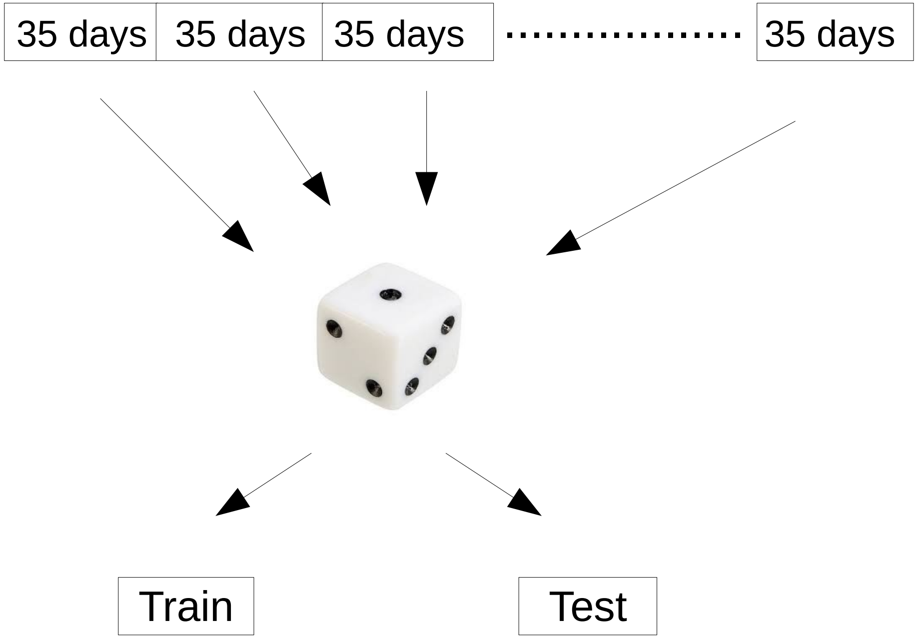
0-30min, 30-60min, 1-2h, 2-3h, 3-6h, 6-12h, 12-24h, 24-48h, 48-72h

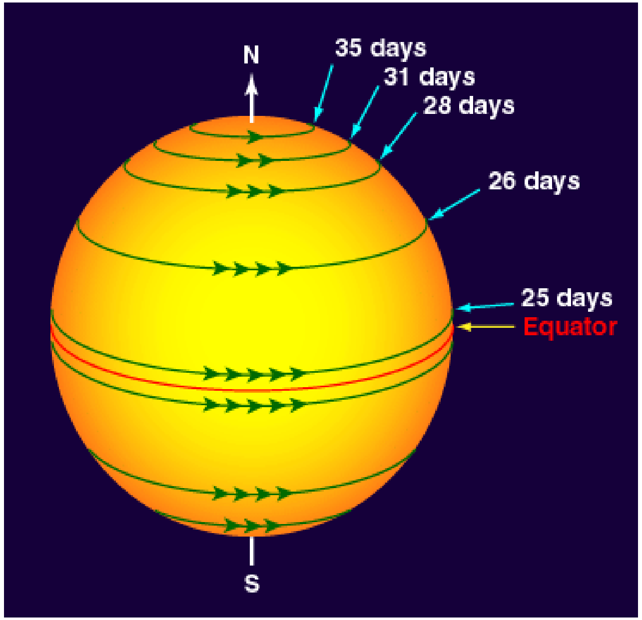
Kp index

Current time value, 0-3h, 3-6h, 6-12h, 12-24h, 24-48h, 48-72h

We distribute data in chunks of 35 days to train and test sets to avoid data leakage and cover solar rotation period

Keep together adjacent times when doing the train/test split for time series.

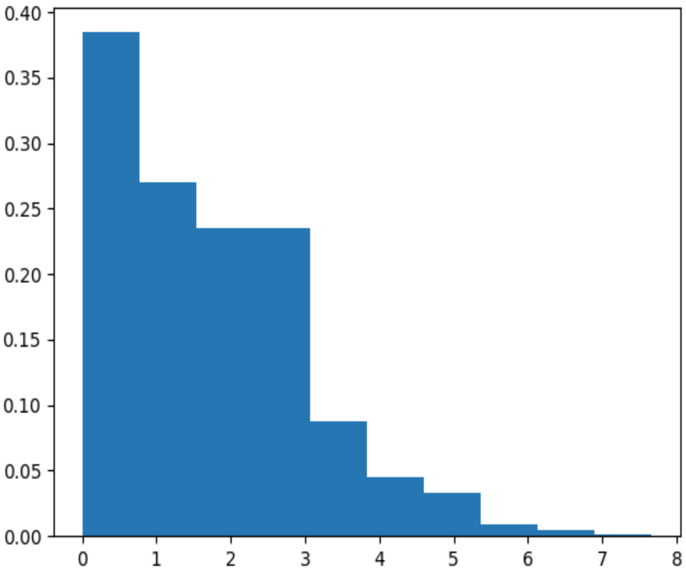




Credits: Nasa

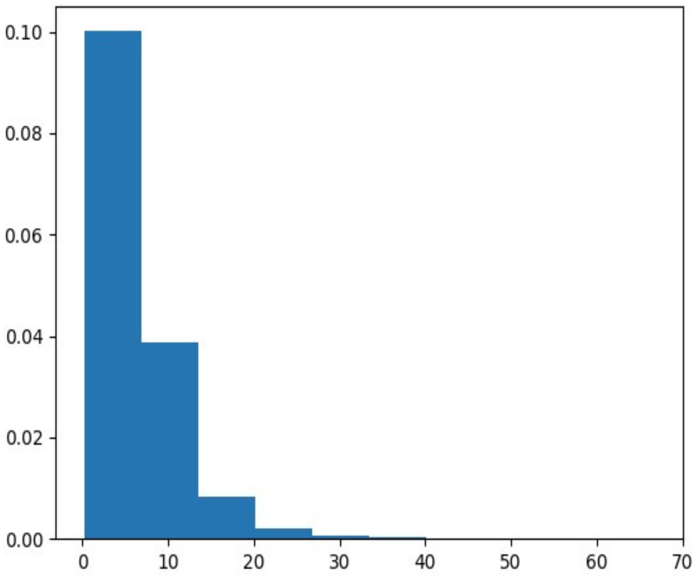
We scale differently the different features since we have different distributions

Kp at given time



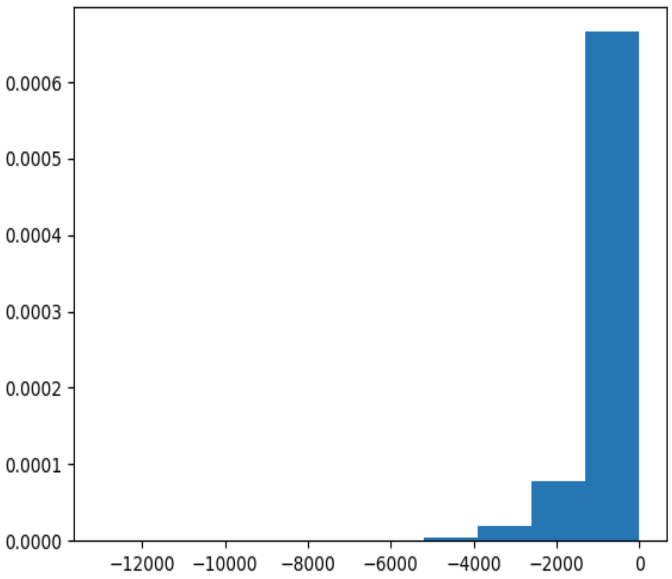
MinMax scaler

ρ_p mean past 3 hours



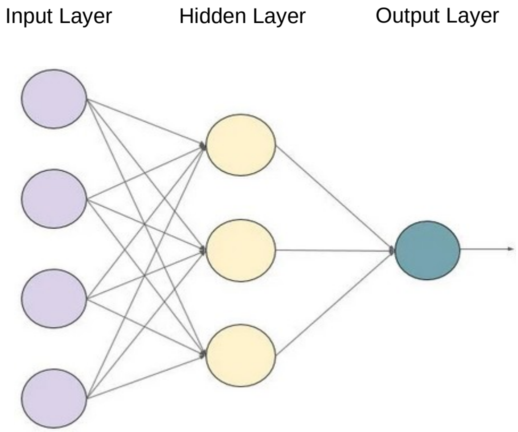
First $\log_e$, then a standard scaler and then a MinMax scaler.

vsw· Bs mean past 3 hours



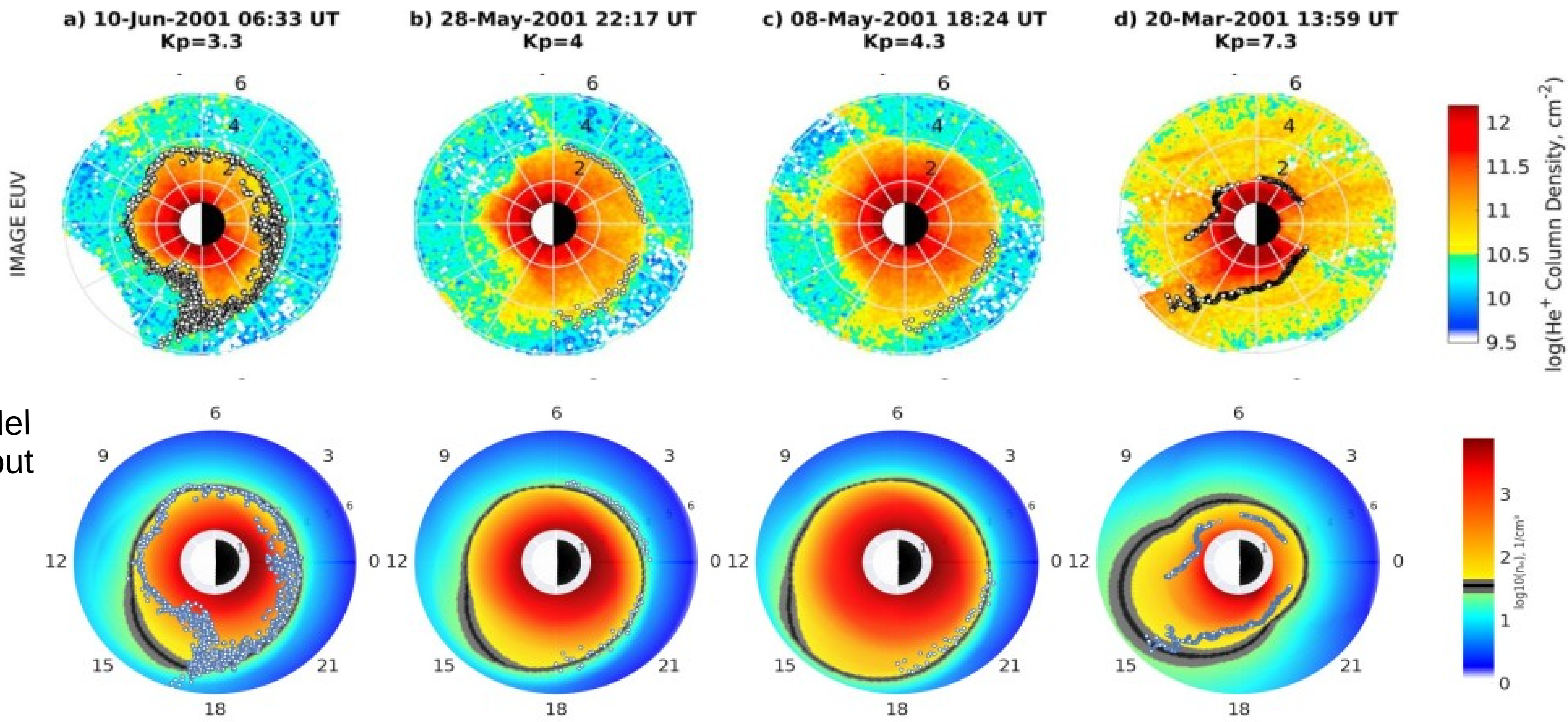
log10 transformation and a MinMax scaler.

We checked several numbers of neurons for a network with 1 hidden layer and 15 neurons gave the best RMSE.



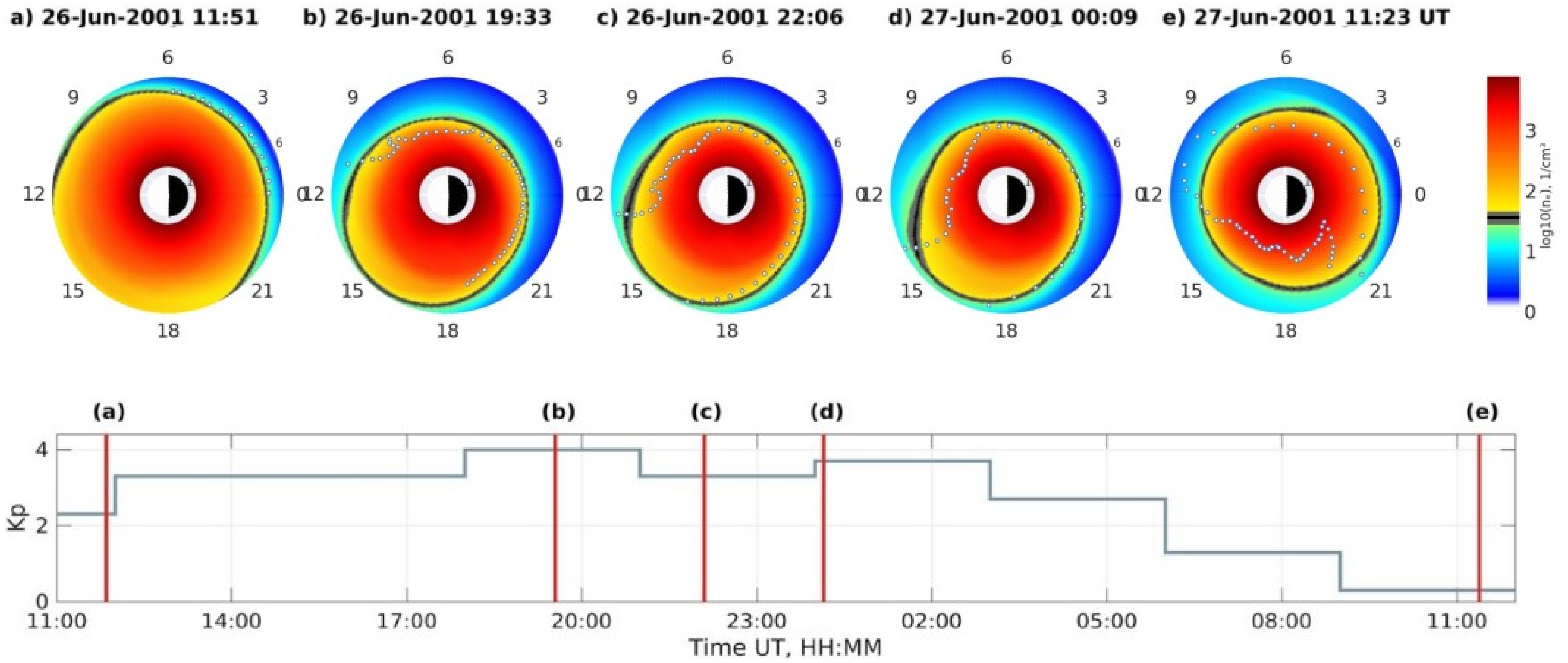
$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(y_i - \hat{y}_i)^2}{N}}$$

We reproduce the main structure of the plasmapause, also during storm times.



Model output

We reproduce the erosion of the plasmasphere and the eastward movement.



Future work

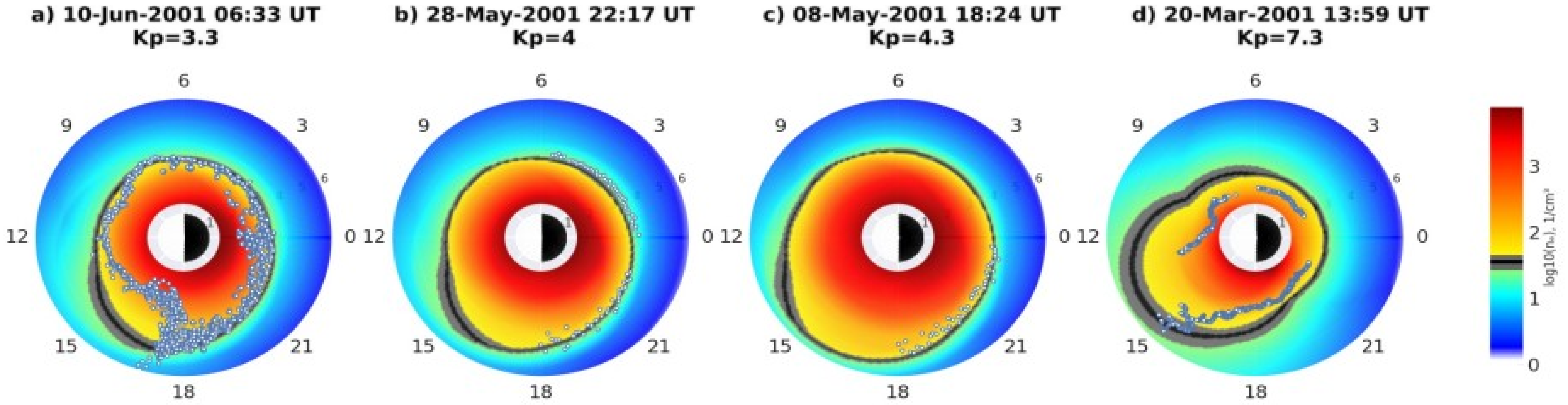
Include the model in the PAGER pipeline.

- Include the model in a docker container
- Check the performance with the PAGER inputs

Try to improve the model

- Add new solar wind features.
- Include regularization
- Try more neural network architectures

We can reconstruct the structure of the plasmasphere, with solar wind and Kp, also during storms.



Questions?!

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