A machine learning framework for the reconstruction of the 3-D ion density distributions in the Earth's cusp

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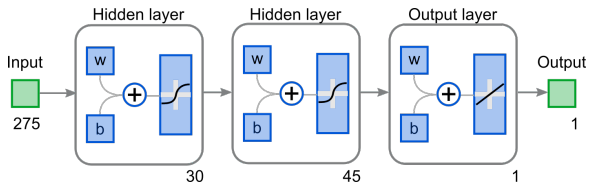
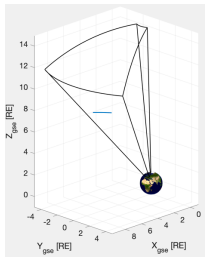
Introduction

- The primary mechanism for transporting mass, momentum, and energy from the solar wind into the magnetosphere is magnetic reconnection, which drives several geomagnetic events on Earth. Several studies demonstrated that the analysis of the time-energy dispersion of ions in the Earth's cusp serves well to infer the location and dynamic properties of dayside magnetic reconnection processes. However, current in-situ measurements at the cusp are often challenging to interpret due to data's spatial and temporal sparsity.
- To overcome this problem, in this work, we generate a machine-learning-based model of the Earth's cusp using CLUSTER mission data acquired from 2001 to 2005 to provide a 3-D structure of ion density.
- We implement an artificial neural network (ANN) using several geomagnetic indexes and solar wind parameters as inputs, and ion densities and energetic flux acquired by the CIS/CODIF instrument onboard the Cluster mission as supervised outputs.

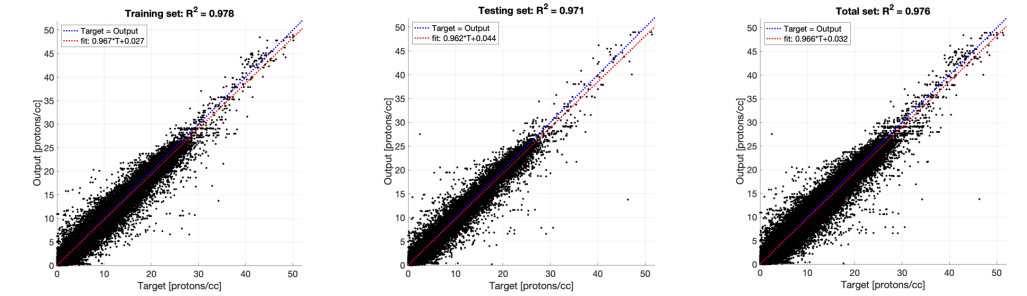


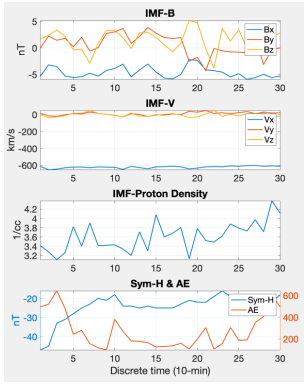
- Input vector has been created with solar wind data and geomagnetic indexes IMF Bx, By, Bz, Vx, Vy, Vz, solar wind density, Sym-H, AE, for 5 hours before a C1 measurement with 10-min resolution.
- Target/output is the H+ density measured by C1 in a given region of interest.

Region of interest

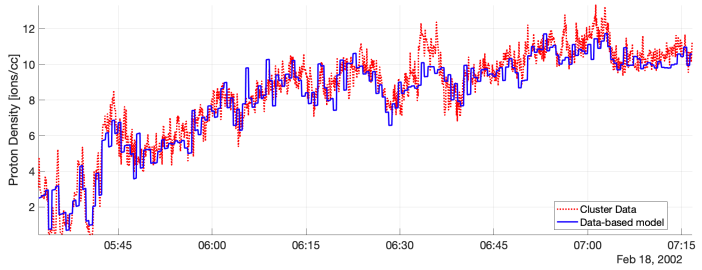


Implementation



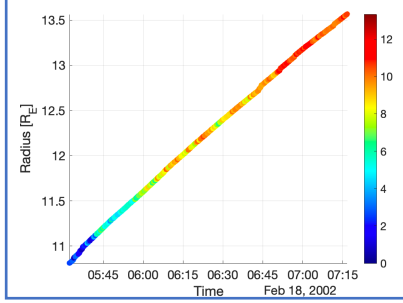


$r, \phi(long), \theta(lat)$

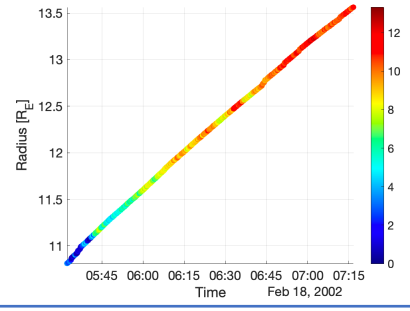


- The left plot shows the input values used to predict the proton density. The right plot shows a comparison between cluster data and the predicted values by the model. Disagreement between time resolution of Cluster data (~8 s) and Omni-web(1min) forms the time-invariant feature in the prediction.

Data-based model

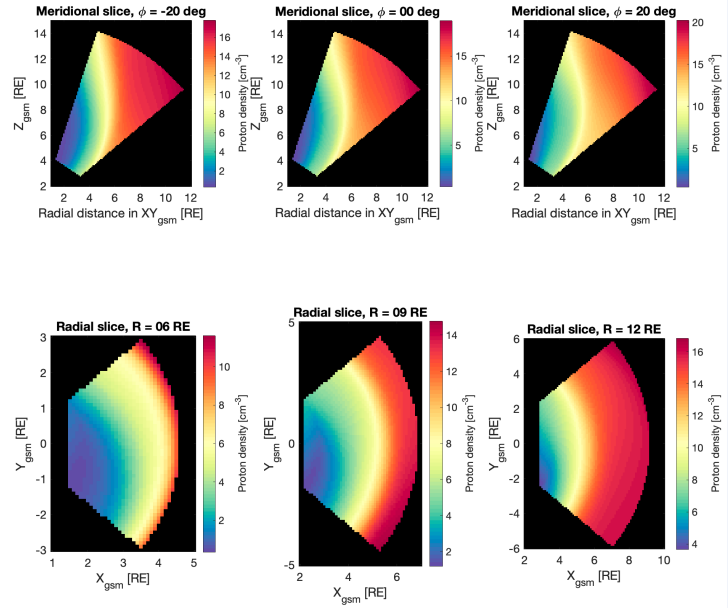


Cluster data



- Comparison of Cluster data and predicted values showing dependence on the spatial distribution.

3-D reconstruction of H+ density



- Three-dimensional estimation of proton density at the Earth's cusp. The model can reproduce the Earth's cusp structure and identify the plasma mantle region.

Future Work

- Future work aims to estimate energetic flux using spectrograms provided by Cluster instruments.
- Also, we intend to study plasma physics within the Earth's cusp by analyzing our ANN results.

References

Lavraud, B. et al (2002) Cluster observations of the exterior cusp and its surrounding boundaries under northward IMF, GRL, 29, 20.

Bortnik,J., et al (2016), A unified approach to inner magnetospheric state prediction, J. Geophys. Res. Space Physics, 121, 2423–2430