Testing the validity of machine learning for ionospheric dynamics identification

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1 Introduction

Behaviours such as Aurora and geomagnetic storms are direct consequences of the Earth's and Sun's magnetic fields interacting and the resulting behaviour of plasma. As the plasma in the sun is heated there is a point where the Sun's gravity can not hold it down, it then travels with the Sun's magnetic field (also known as the interplanetary magnetic field, IMF) and out into the solar system as the solar wind. Such highly energetic material would normally rip the atmosphere of a planet into space. However, planets such as Earth have a substantial magnetic field creating an area around the planet in which the solar wind is excluded, this is known as the magnetosphere. When the solar wind meets the Earth's magnetosphere a bow shock forms. Compression of the IMF and the magnetosphere causes a process called reconnection (Occurring at the red cross in Fig. 1), here the closed field lines of earth 7 are opened, as like 3, to the IMF allowing plasma from the solar wind to enter the magnetosphere along the open field lines (marked by orange in Fig. 1), allowing events such as Aurora to form. The effect of this reconnection is felt in the ionosphere as the open field lines pass through it (See Fig. 2a), and are known as pulsed ionospheric flows or PIFs.

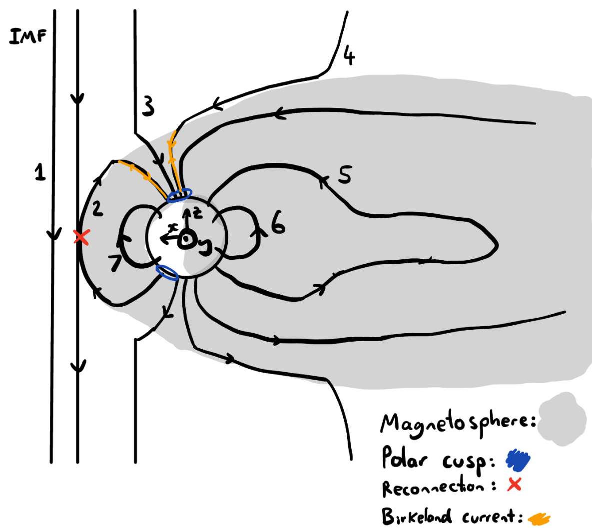
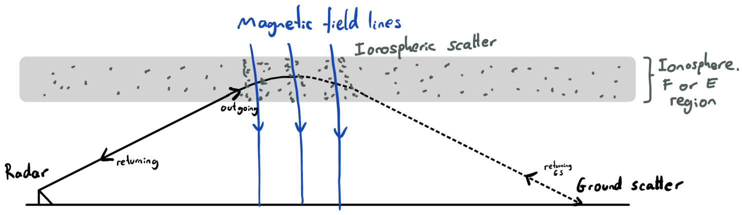
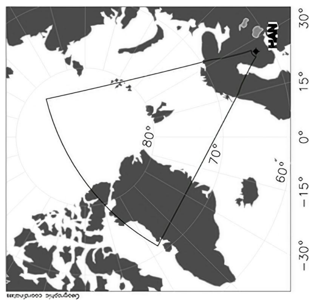


Figure 1: Diagram of the IMF, magnetosphere interaction. Magnetic field lines are coloured black and Sun is to the left of the diagram. Circled numbers in the text i.e. 3 align with the numbers in this Figure.



(a) Diagram of the operations of the Hankasalmi Cutlass radar. In the case of PIFs the blue magnetic field lines carry reconnection signatures.



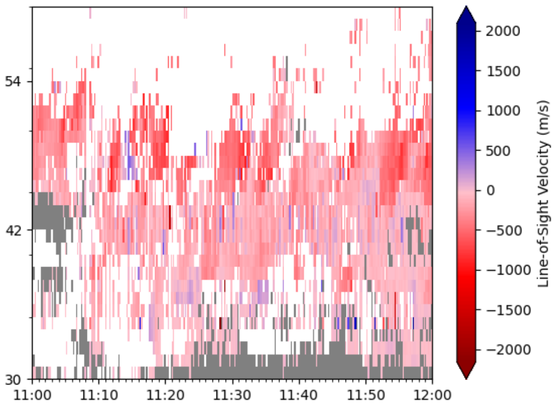
(b) FOV of the Hankasalmi Cutlass radar

Figure 2: Diagrams describing the operation and location of the Hankasalmi Cutlass radar

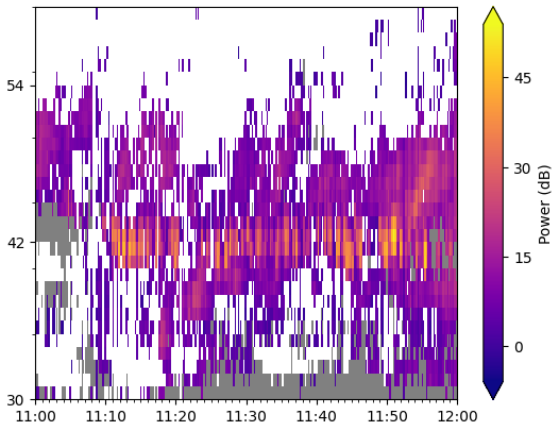
The signature of recconection in the ionosphere can be observed using the Hankasalmi Cutlass radar in Finland, that covers part of the Northern pole, See Figure 2b. The operation of this radar, outlined in Figure 2a, involves projecting radio waves into the ionosphere. When returning signals are received it is a sign that electron density structures are present in the ionosphere, resulting in so called ionospheric scatter (IS). PIFs are one type of IS that can be observed, and are identified by pulsed movement of IS away from the radar (resulting in negative velocities) combined with power enhancements, an example can be seen in Figure 3a and 3b. The focus of this project is to test the validity of using machine learning to automatically identify PIFs within this data, something which is currently done manually.

2 Results and conclusion

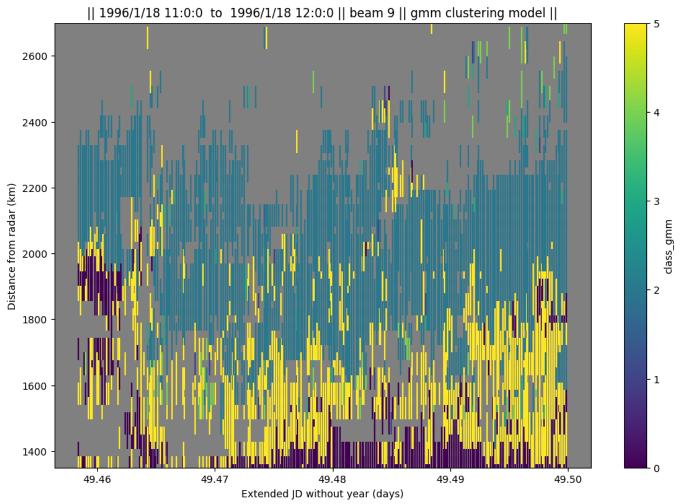
Machine learning is a subset of artificial intelligence that involves training algorithms to learn from data and make predictions or decisions based on that learning. In this project several methods where tested, this summary only outlines clustering due to its effective results. Clustering is the process of grouping data points that are similar to each other based on similar characteristics or properties. It's like sorting a pile of different items into smaller groups based on their similarities. The project involved programming a Python toolkit to help with the experimenting phase, which can be found at this **GitHub**. This was used to test the results of several clustering methods, Gaussian Mixture Models (GMM) was found to be the most effective. The results of it clustering on data containing a PIF can be seen in Figure 3c.



(a) Time range plot of velocity.



(b) Time range plot of power.



(c) Time range plot of GMM cluster label.

Figure 3: Time range plots of a PIF with multiple parameters. From fitted radar data. y axis in a and b is rang gate, analogous to distance from radar

The resulting clustering captures the dynamics of the PIF well, the cluster with label 2 (indicated in blue) clearly encapsulates the velocity and power patterns seen in Figure 3a and 3b respectfully. Quantitatively the model classifies velocities ranging from 500 to -1250 m/s and Magnetic Latitudes from 83.405N to 73.56N, almost perfectly aligning with observations of PIFs by [Provan et al., 1998]. Overall, the feasibility of machine learning has been tested and everything points to its potential in this task and hopefully it promotes future use in the field of space plasma physics.

References

[Provan et al., 1998] Provan, G., Yeoman, T. K., and Milan, S. E. (1998). Cutlass finland radar observations of the ionospheric signatures of flux transfer events and the resulting plasma flows. In *Annales Geophysicae*, volume 16, pages 1411–1422. Springer Verlag Göttingen, Germany.