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NAM2021

Preliminary study using Machine Learning techniques of electric field and conductivity models in relation to high-latitude thermospheric neutral winds and temperature

Introduction

Existing, commonly used, models of high-latitude **electric fields** and **conductivities** have been derived from ground-based radars and satellites since the 1970s.

These have largely used measurements of plasma densities and velocities, or magnetic field measurements to derive the electric field, or the conductivity, individually and separately. These models are then used as drivers in coupled ionosphere-thermosphere models, which then calculate the response of the whole upper atmosphere system.

However, the **feedback contribution of the neutral atmosphere is not incorporated** into these electric field and conductivity models. So each new model step uses an unmodified driver.

EISCAT antenna outside Kiruna (https://eiscat.se/about/)

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Starting Point

I have just finished my first year of training and I am bringing all the new techniques I have learnt into my research.

I have been starting to write modules to automate the process of getting data from different satellite sensors. This process involves decodification of data, coordinates and numerical conversions as well.

I have also included parts of the International Geomagnetic Reference Field (IGRF) code released by NOAA (https://www.ngdc.noaa.gov/IAGA/vmod/igrf.html) into my Python program.

12am to 1 am (1 hour) - 01 Jan 2001

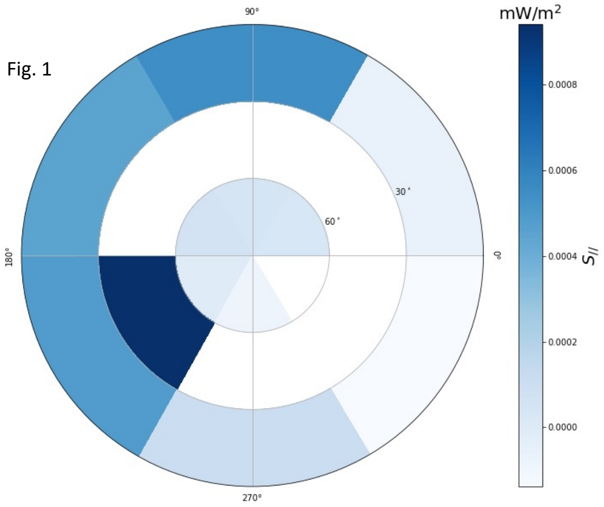


Fig. 1

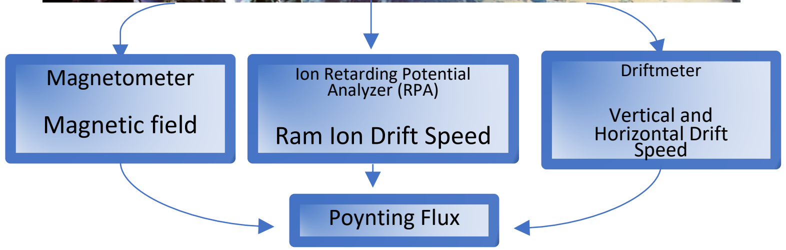
$$\mathbf{S} = (\mathbf{E} \times \delta\mathbf{B})/\mu_0$$

$$\mathrm{S}_{\parallel} = \left(\mathrm{E_x}\delta\mathrm{B_y} - \mathrm{E_y}\delta\mathrm{B_x}\right)/\mu_0$$

$$\mathbf{E} = (-\mathbf{V} \times \mathbf{B}_{\mathrm{IGRF}})$$

$$\delta\mathbf{B} = \mathbf{B}_{\mathrm{meas}} - \mathbf{B}_{\mathrm{IGRF}}$$

Fig. 2



Magnetometer

Magnetic field

Ion Retarding Potential Analyzer (RPA)

Ram Ion Drift Speed

Driftmeter

Vertical and Horizontal Drift Speed

Poynting Flux

https://www.afspc.af.mil/About-Us/Fact-Sheets/Article/249019/defense-meteorological-satellite-program/

DMSP Satellite Data

DMSP is the first satellite I have tested my code with. I am able to read all its built-on-detectors and store data into a database for further calculation.

My physical observable at this stage is the **Poynting vector** component parallel to the Earth magnetic field.

In order to compute the Poynting flux, I need to get data from the Magnetometer, Ion Retarding Potential Analyzer (RPA) and Driftmeter (Fig. 2).

Poynting Vector

I need to construct the velocity **V** vector getting data from the RPA and Driftmeter. Thanks to the IGRF code I have included, I have been able to get the $\mathbf{B}_{\mathrm{IGRF}}$ field at the satellite position and calculate the electric field **E**. In order to include the neutral wind into the equations, the actual electric field to computed should be:

$$\boxed{\mathbf{E} = (-\mathbf{V} + \mathbf{U}) \times \mathbf{B}_{\mathrm{IGRF}}}$$

Where **U** is the neutral wind velocity.

With $\delta\mathbf{B}$ from the Magnetometer, it is possible to compute the Poynting flux parallel to the Earth's magnetic field.

Poynting Flux

The pie chart (Fig. 1) shows the northern pole binned into equal areas of 60° longitude and 30° latitude.

The average Poynting flux is computed with DMSP data taken within an hour and it tends to zero in quiet days. The Poynting flux values are expected to become negative on most disturbed day. Negative values on the color bar indicate Earth-directed Poynting vector.

Next step is to compute the averaged Poynting flux in a Magnetic Local Time system of coordinates, covering a long period of time (i.e. years) and find the quietest and most disturbed day.

Why?

The Poynting vector is a measure of the electromagnetic energy transfer to a system.

Its flux is then a measurement of the flow of electromagnetic energy into our atmosphere.

$\nabla \cdot S$ manifests as Joule heating and acceleration of the neutral gas. This is due to the kinetic energy of the ions which collide with the neutrals causing atmospheric disturbances, drives ions and neutral upwelling and neutral atmospheric expansion.

Some observations have seen positive values of Poynting flux. It means an energy flow going out the atmosphere and this could be caused by the neutral winds . (Ref. Anasuya L. Aruliah et al. - Consequences of geomagnetic history on the high-latitude thermosphere and ionosphere: Averages - https://doi.org/10.1029/1999JA900334)(Ref. Gary et al. - Field-aligned Poynting flux observations in the high-latitude ionosphere https://doi.org/10.1029/93JA03167)

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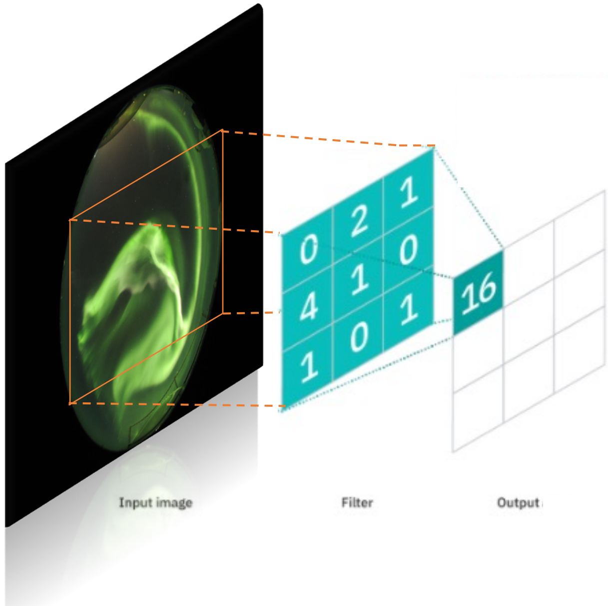
Machine Learning

The next step is getting Machine Learning into my research.

I want to start with imaging classification of Auroras taken by the Kiruna all-sky camera, located in Sweden.

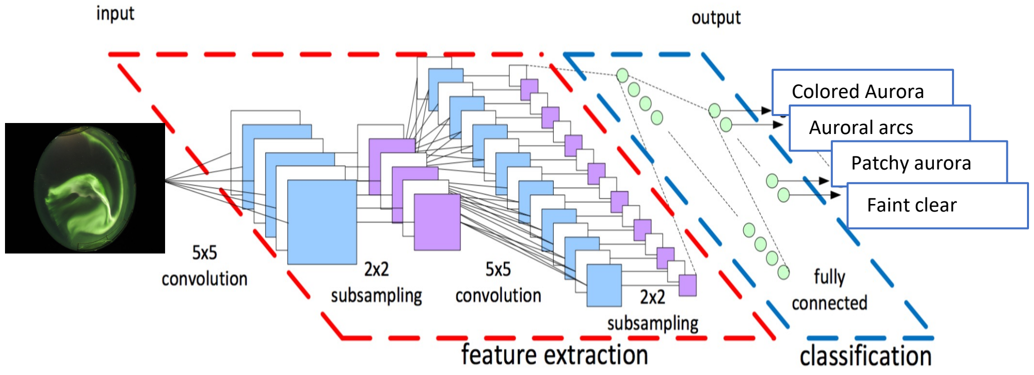
The aim is to train a Convolutional Neural Net (CNN) in order to classify Auroras and predict the altitude at which it has occurred in the atmosphere, exploiting the correlation between colour and depth.



Convolution Neural Network

The Convolution Neural Network is a Machine Learning algorithm widely used for imaging classification.

The CNN algorithm reduces the parameter space without losing features which are critical for getting a good prediction.



https://medium.com/data-science-group-iitr/building-a-convolutional-neural-network-in-python-with-tensorflow-d251c3ca8117

CNN to ANN

The actual classification is made by a fully connected Artificial Neural Network.

The ANN input uses all features extracted from the image after the convolution.

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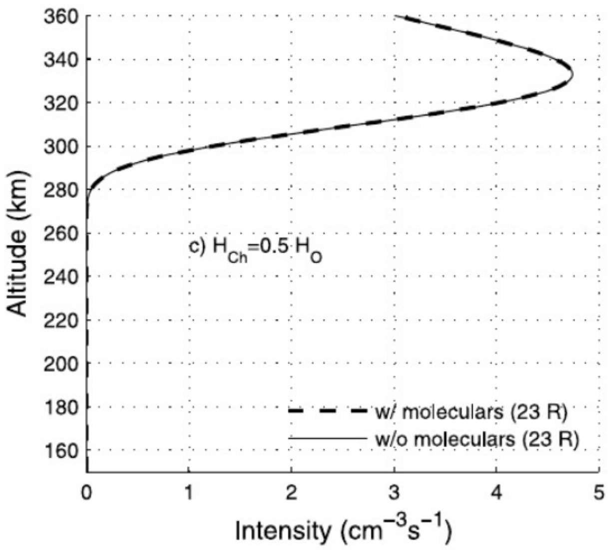
From light intensity to Altitude

The intensity of the light emission in the upper atmosphere is an important feature which can be extracted from images.

$$I_R^{\triangle} = \frac{A_{1D}\mu_D \gamma_2 [O_2]_0}{lP} n_{e0} \times \exp\left[\frac{z}{H_{O_2}} + \frac{1}{2}\left(1 + \frac{z}{H_{Ch}} - e^{z/H_{Ch}}\right)\right]$$



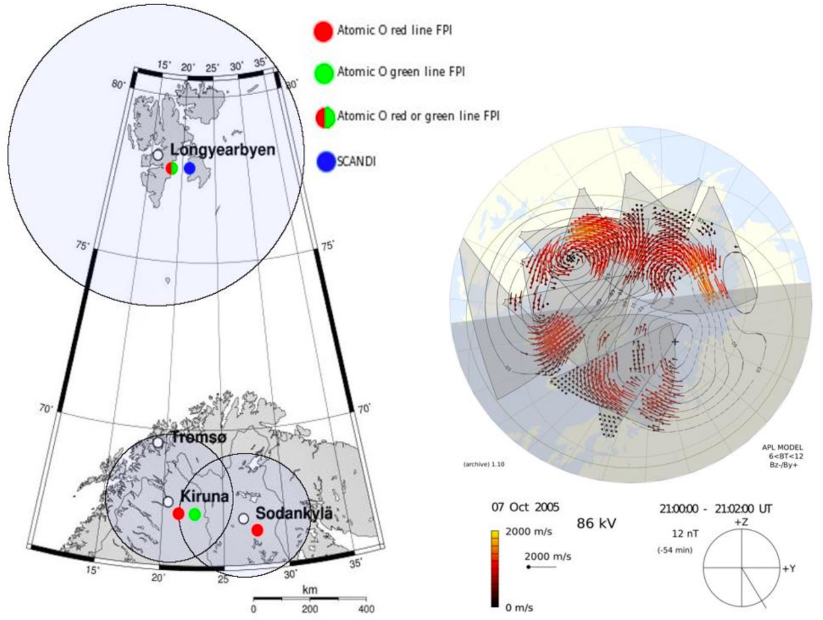
Michael N. Vlasov et al. - Modeling of airglow and ionospheric parameters at Arecibo during quiet and disturbed periods in October 2002 - https://doi.org/10.1029/1999JA900334

Neutral Atmosphere

At the altitude identified by the CNN, I will look for signatures of feedback between electric field and conductivities in EISCAT radar and satellite databases.

A step forward will be looking at the contribution of the neutral atmosphere to the coupled system, in terms of neutral dynamics and temperatures and to the chemical changes due to upwelling of the neutral atmosphere measured by Fabry-Perot Interferometers (FPI) co-located with the EISCAT radars.

UCL have FPIs at Kiruna and Sodankyla which have overlapping fields-of-view. This allows calculation of the vector for the neutral wind. It is also possible to estimate the peak emission height by comparing intensities and neutral temperatures from the two overlapping line-of-sight measurements.



Network

Arctic Scandinavia has a rich network of ground instrumentation: UCL FPIs at Kiruna and Sodankyla, the EISCAT incoherent scatter radars at Longyearbyen and Tromsø , the UCL narrow-field FPI and wide-field FPI (the Scanning Doppler Imager - SCANDI) at Longyearbyen the polar cap along with the Auroral Structure and Kinetics (ASK) imager.

The strength of this network is the overlapping geometry of FPIs, ASK, and EISCAT radars, allowing independent measurements of the neutral and ionised gas within common volumes of gas.

On the right is shown the SuperDARN coherent scatter radar network that overlapped the Scandinavian region until recently. This derived the high-latitude electric field from measurements of the ion velocity **V**.