

Enhancing the Predictability of GNSS Scintillations

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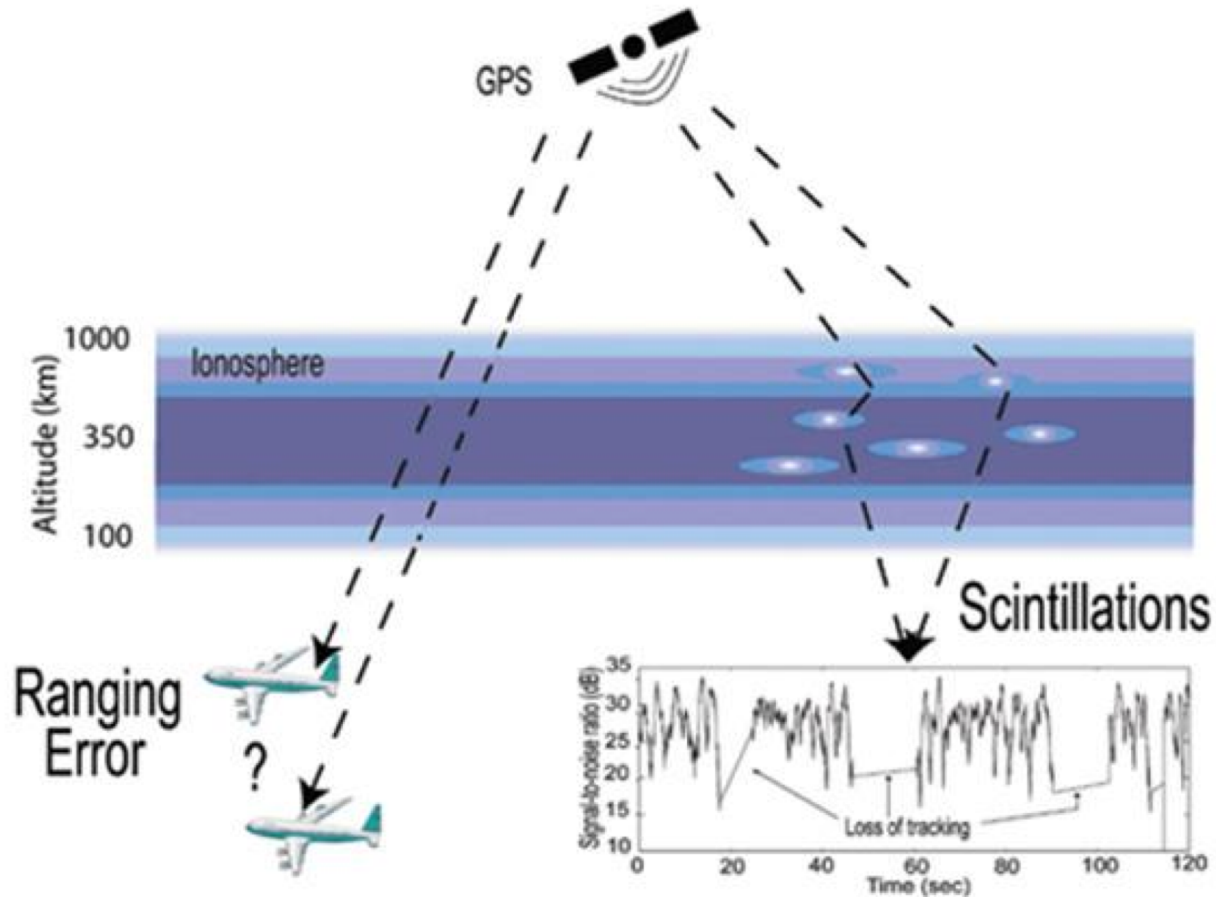
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* : Equal Contribution

CEDAR 2020

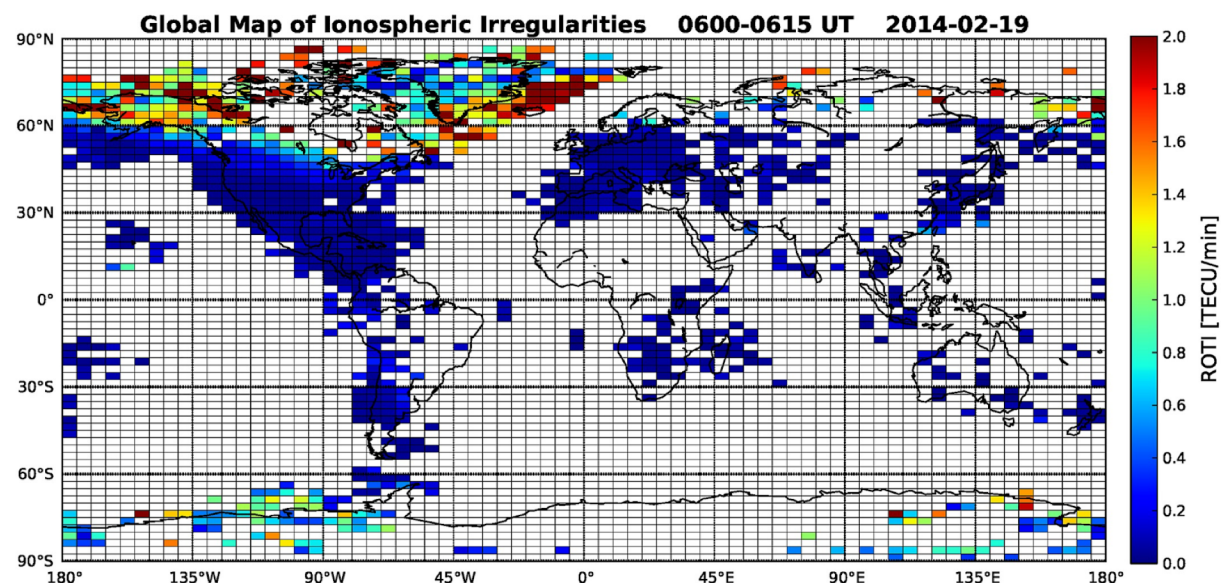
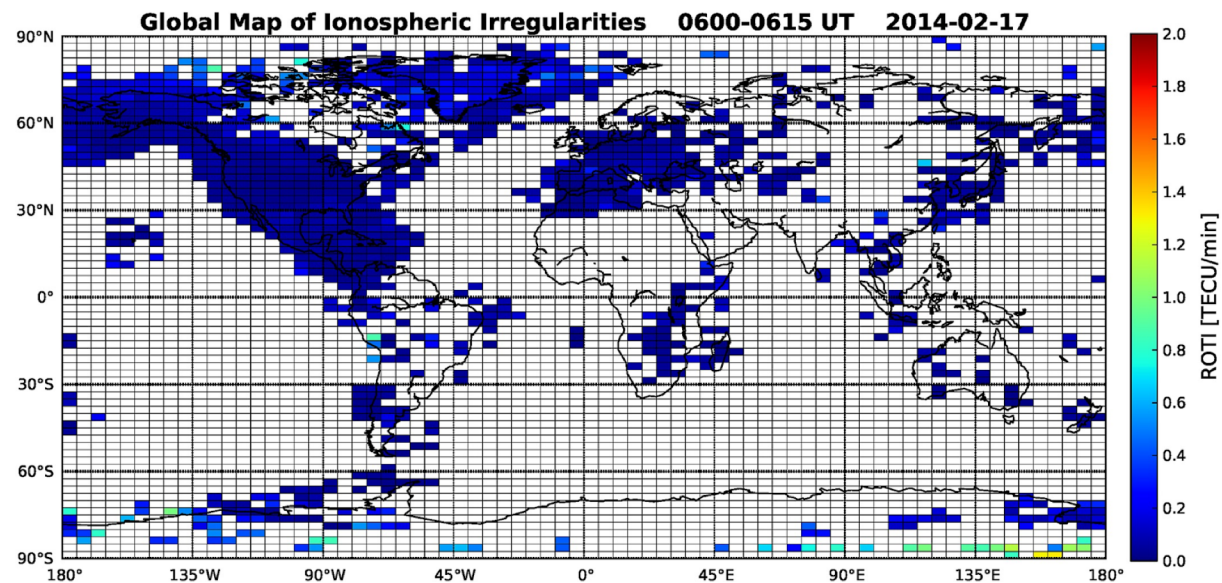
Ionospheric Scintillations



- Loss of Lock
- Low Signal to Noise Ratio

Space Weather

Two global maps of ionospheric irregularities measured in ROTI produced using IGS and U.S. CORS GPS data collected during 06:00–06:15 UT, February 17 (top) and 19 (bottom), 2014, respectively

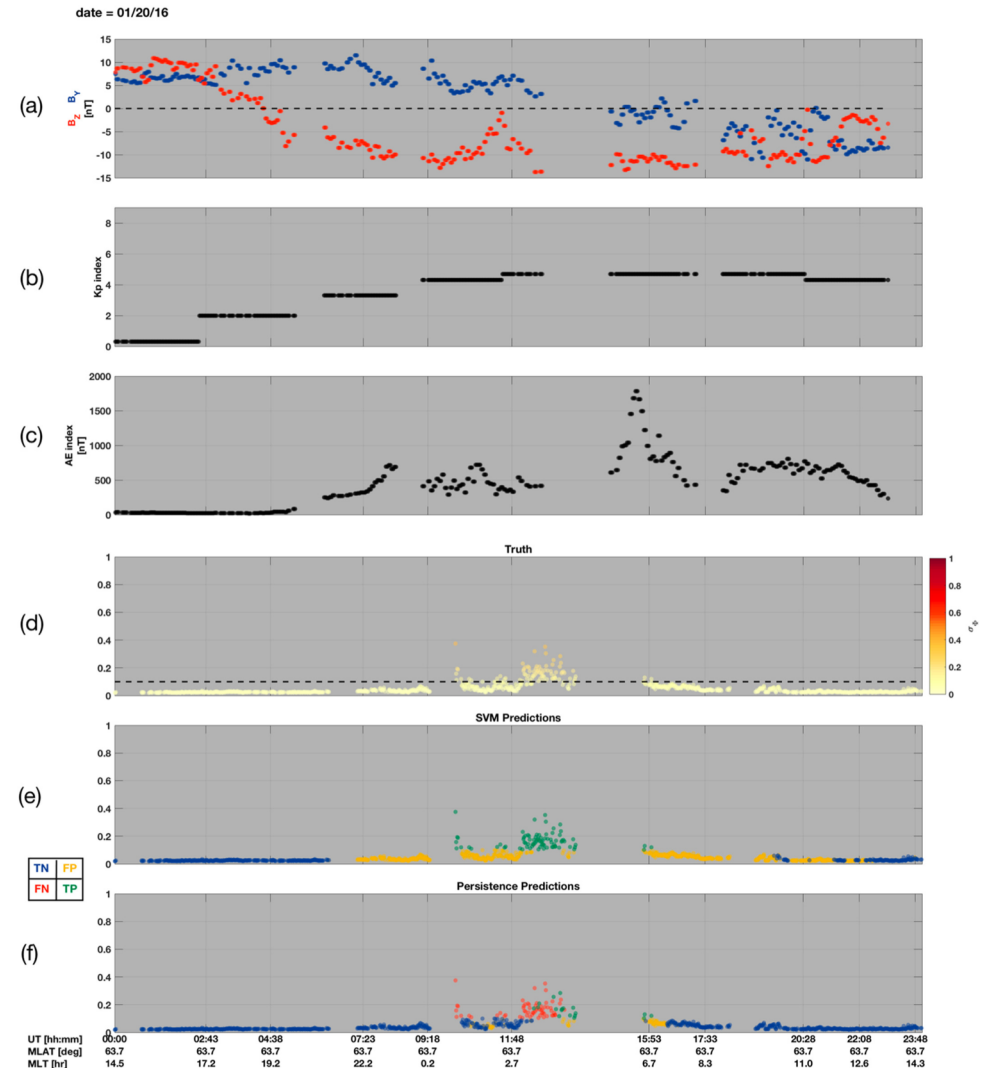
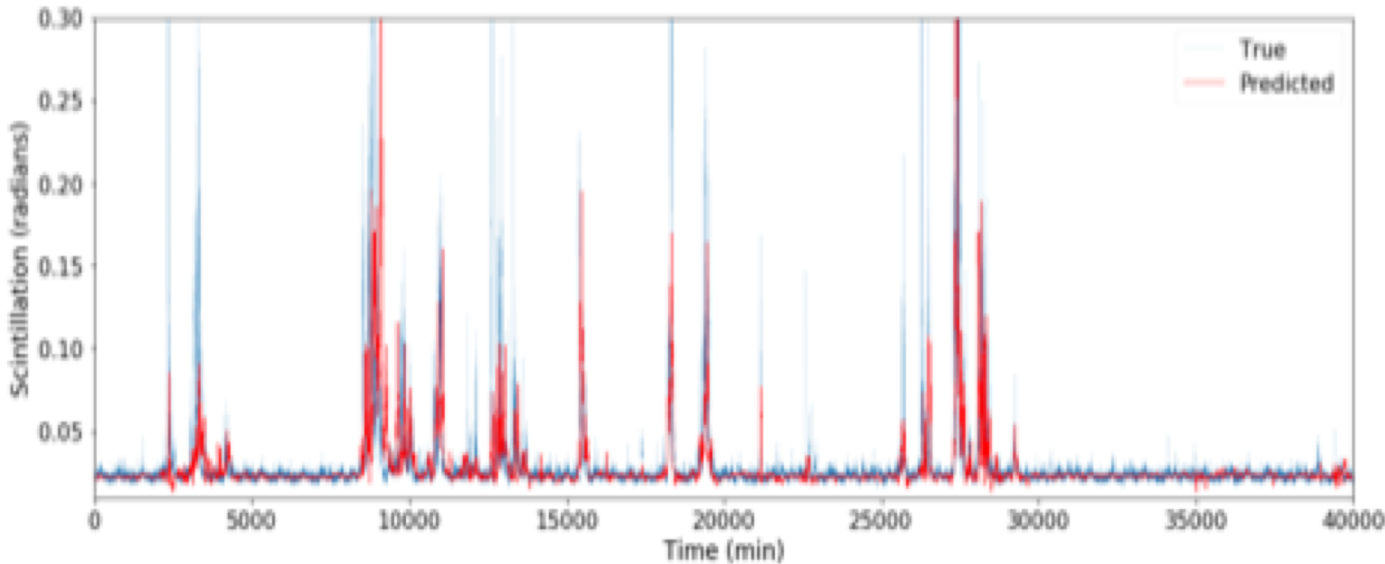


Pi, X., Iijima, B. A., and Lu, W. (2017) Effects of Ionospheric Scintillation on GNSS-Based Positioning. *J Inst Navig*, 64: 3– 22. doi: [10.1002/navi.182](https://doi.org/10.1002/navi.182).

No physics based model to predict
GNSS/GPS scintillations at specific times
and locations


Previous work

- Using solar, magnetospheric and ionospheric data
- Support Vector Machine (McGranaghan et al., 2018) - TSS - 0.49
- NASA FDL 2018: Random Forests and MLP (implemented on one station MCM only) : TSS 0.84



Supervised Approach

Data Description

 : Global (OMNIweb - NASA/NOAA database) 1 min

• Solar

- Vsw, Psw
- IMF Bx, By, Bz, Clock Angle
- F10.7
- Proton Flux, GOES X-ray Flux
- EUV from SDO - FDL 2018 SDO Team

• Geomagnetic Indices

- Kp, AE, DST, SymH, Newell CF, Borovsky CF

Ds : Satellite-Ground Pair Specific (CHAIN - 1 min)

- TEC, dTEC, SI, spectral slope
- $\sigma\phi$, S4 (vertically projected)

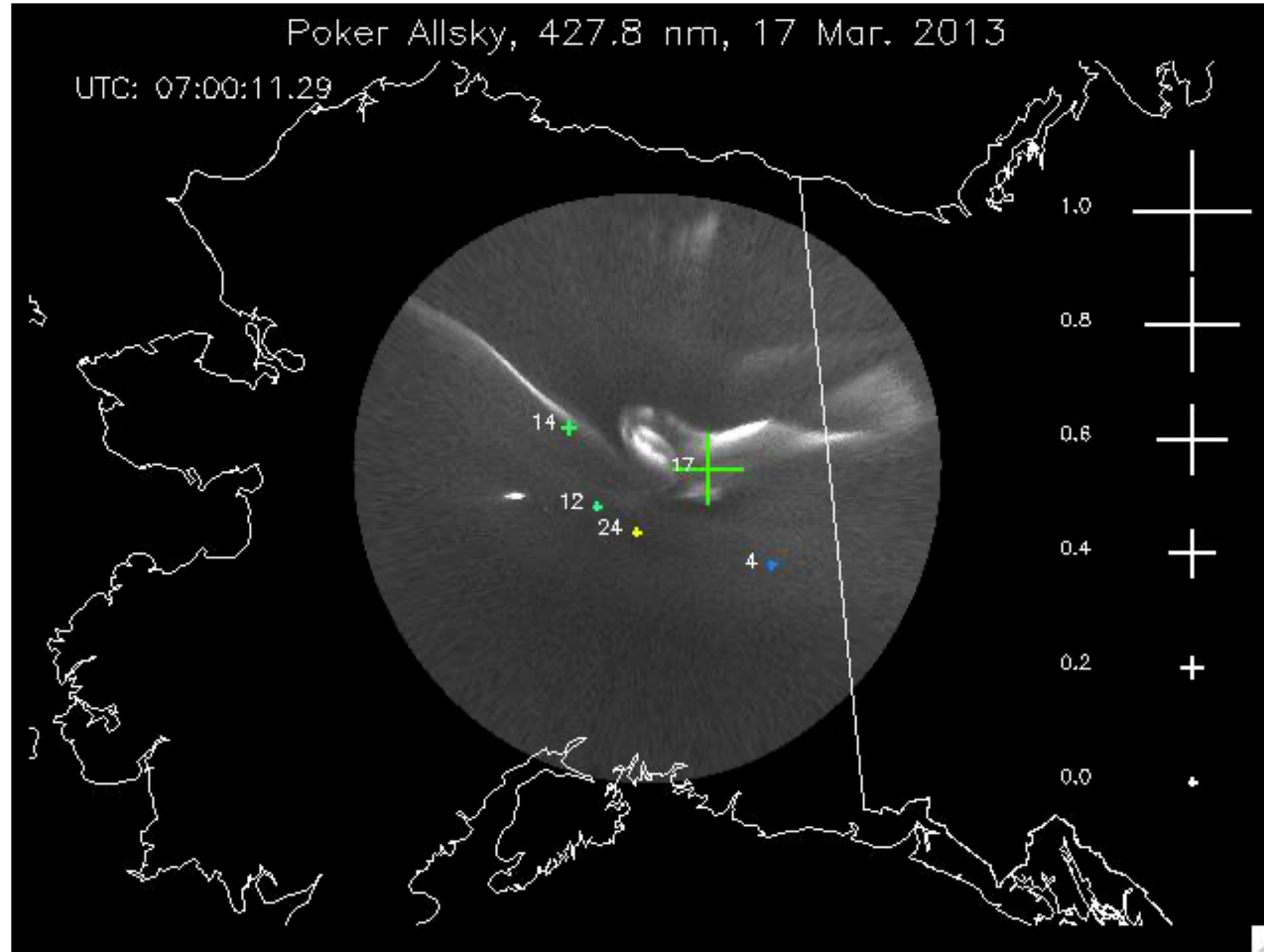
Dg : Ground Specific

- Magnetometer - (Bx,By,Bz) (**CARISMA** - 1 sec.)

Di : Ionosphere

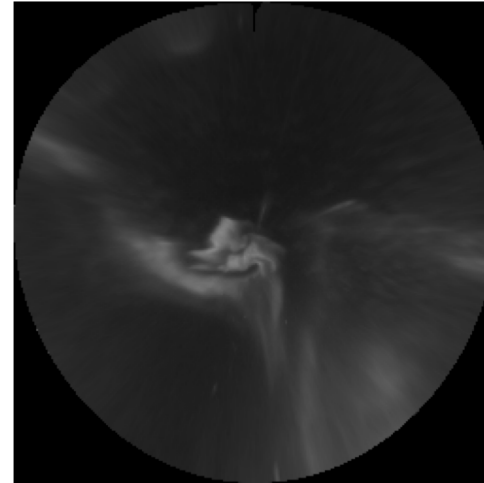
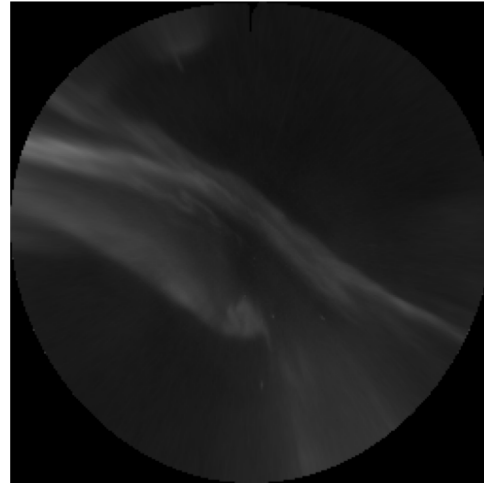
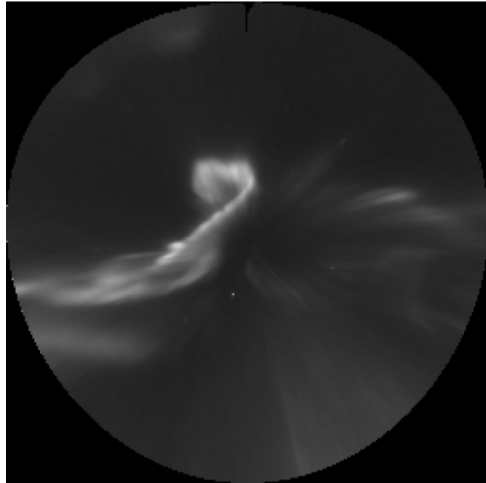
- *Imaging* - Auroral Images (**THEMIS**) ~ 1 sec.

Correlation of Auroras and Scintillations



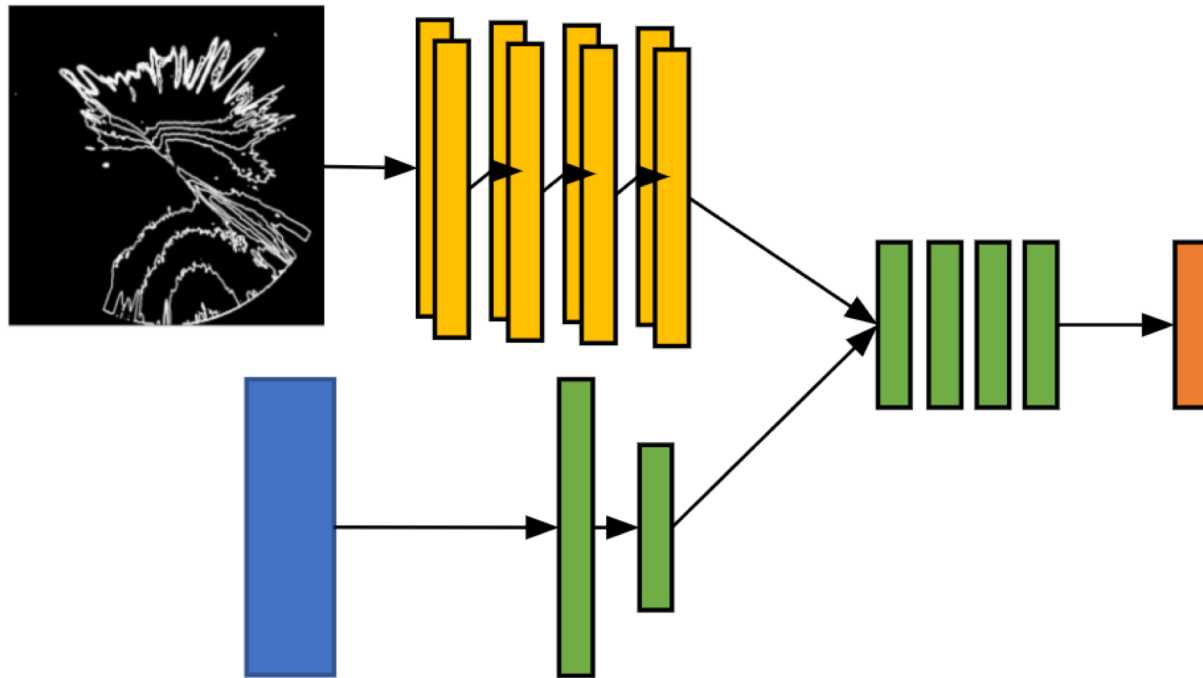
Courtesy:
Donald Hampton, University
of Alaska, Fairbanks

Imagery Dataset



- Images from Midnight \pm 3h
- Projected auroral images
 - Correcting fisheye lense
 - Projecting to 110km
 - Moon/Clouds
- Edge Detected Contours
 - Contours \sim Quantizing
 - Highlights structure of aurora

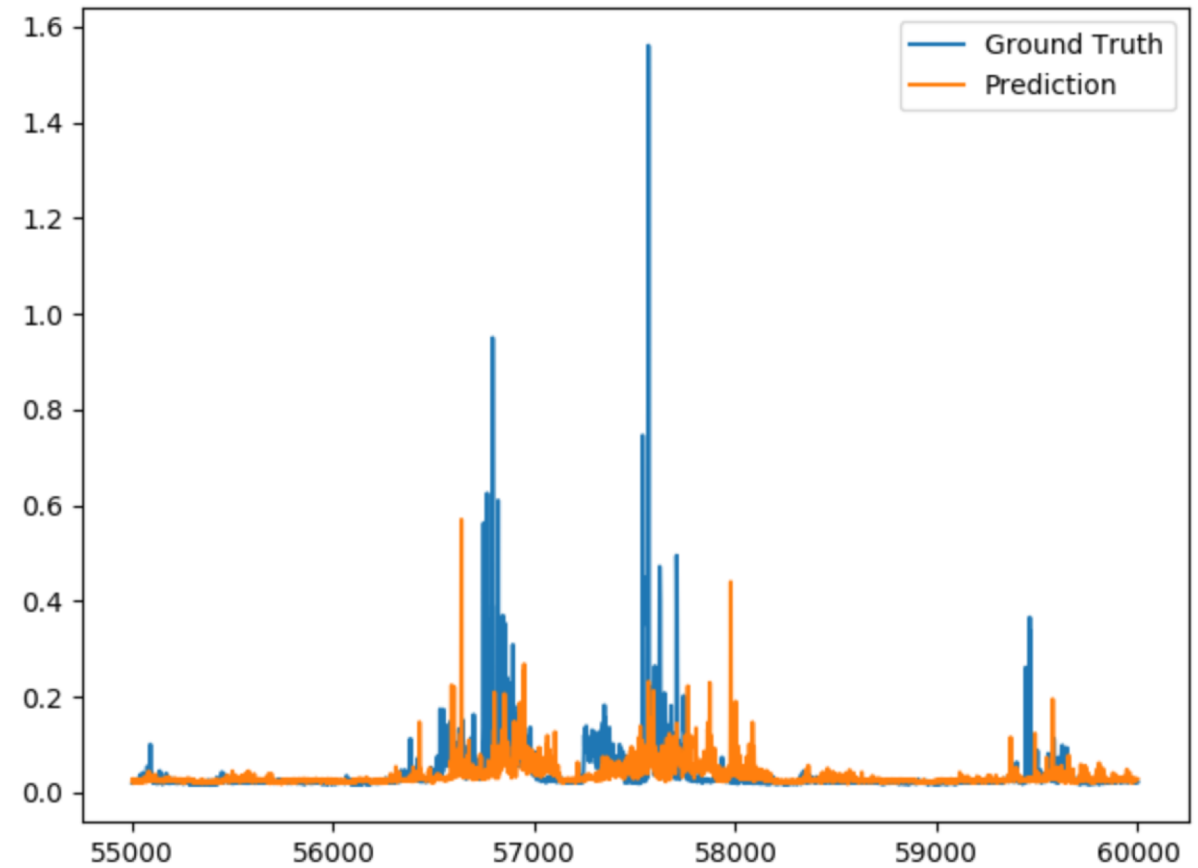
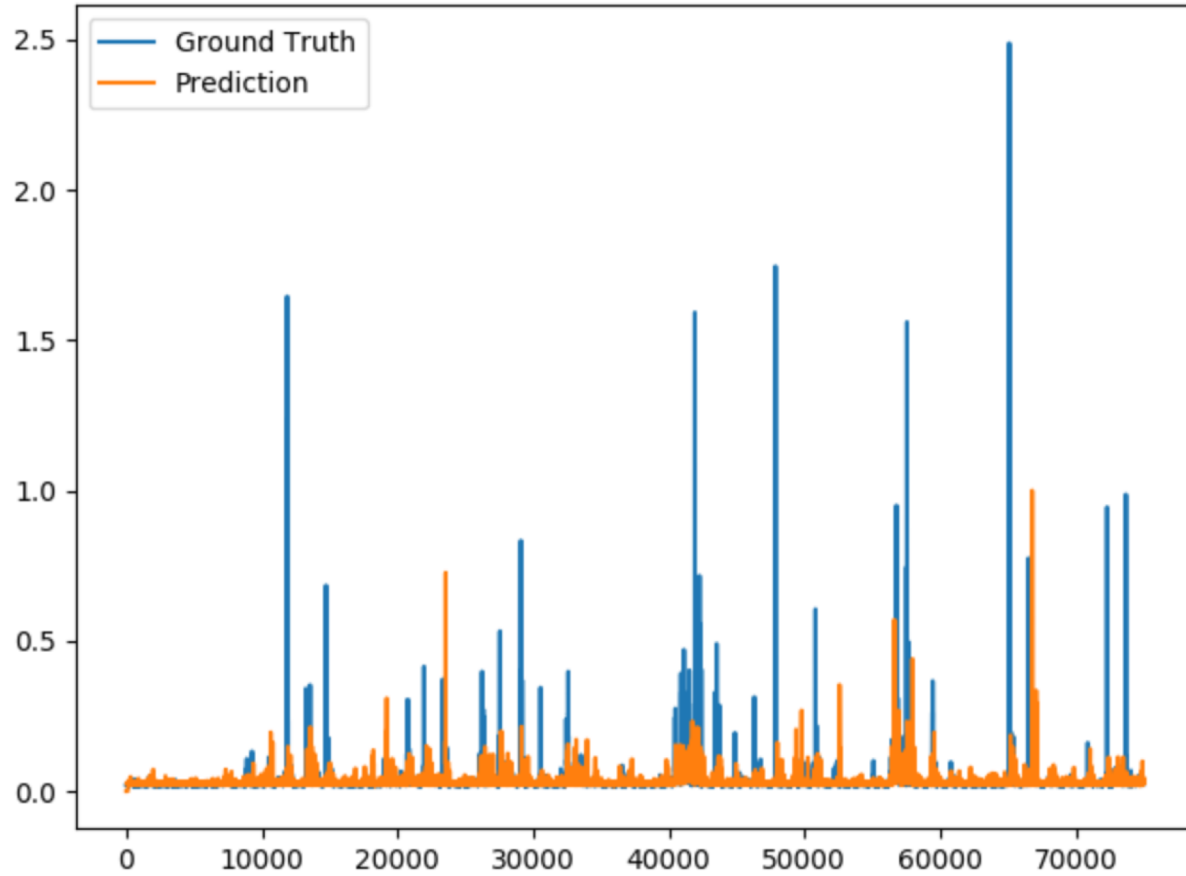
Predicting Scintillations – With Images



- Fully Convolutional Network
- History Window – 120 mins
- Prediction – 60 mins
- Inputs both physical measurements and images
- Images in form of contours
- Trained on 2 months
- Tested on 2 months

Predicting Scintillations

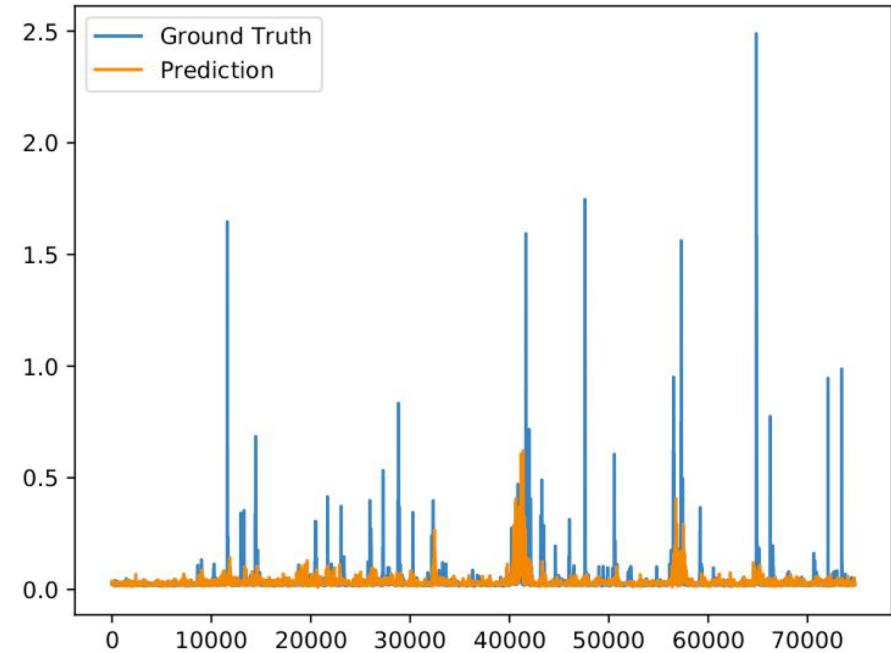
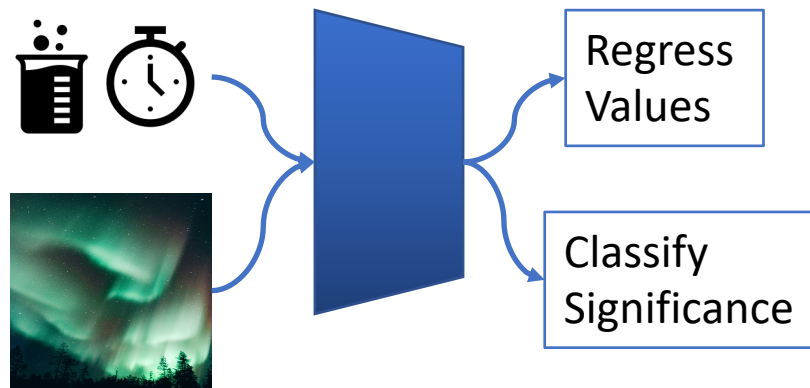
Heidke Skill: 0.21



Predicting Scintillations

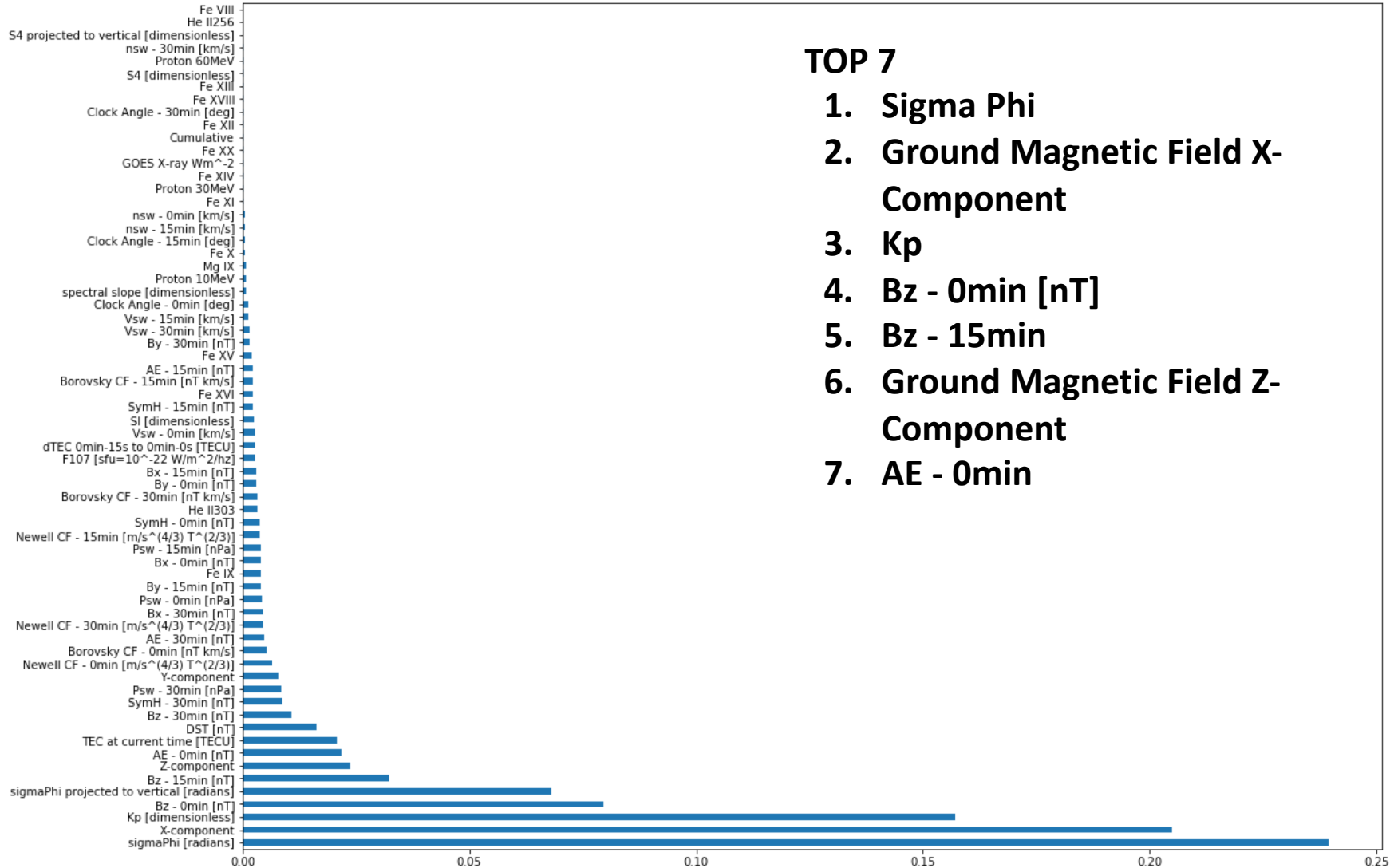
Heidke Skill: 0.83

Multi-task Machine Learning



Feature Importance

Gradient Boosting - Solar Data, CHAIN, CARISMA, SDO MAE : 0.16585983543820343

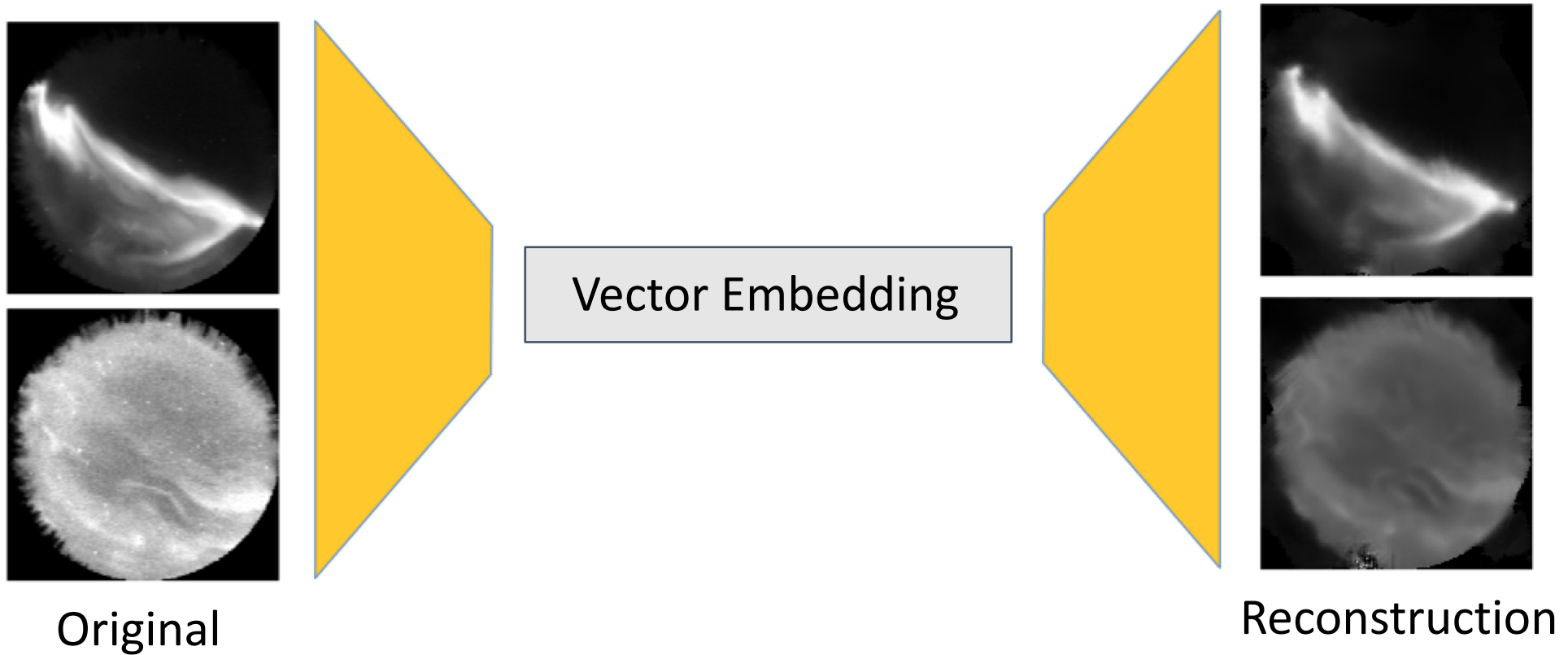


HIGH IMPORTANCE -

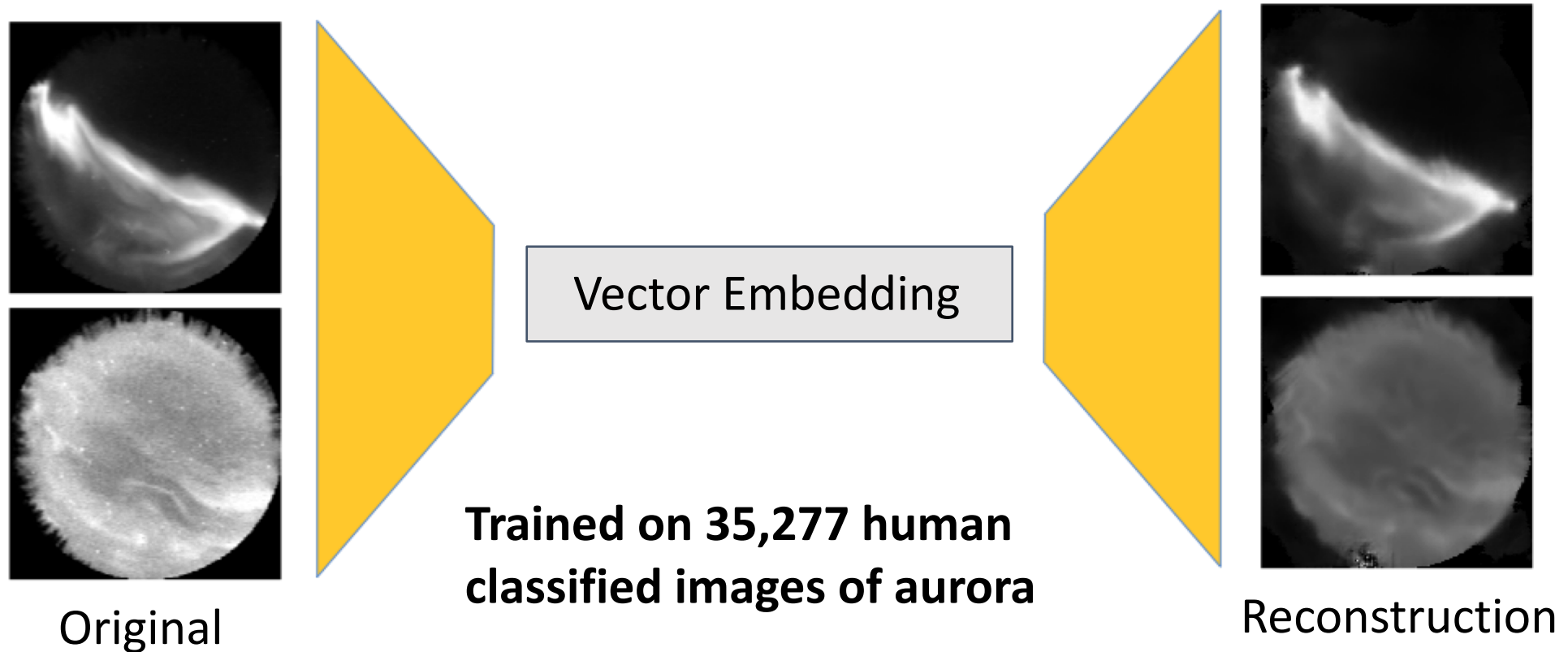
- Ground Magnetic Field - Bx.
- Standard deviation in dTEC over the last 30 minutes.
- Sigma Phi integrated over last 10 minutes.
- Solar wind Bz integrated over last 15-30 minutes.
- SDO wavelength He II - 303 and Fe IX.

Unsupervised Approach

AutoEncoder Analysis

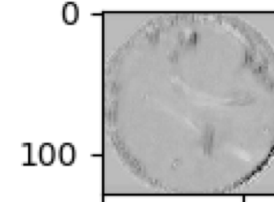
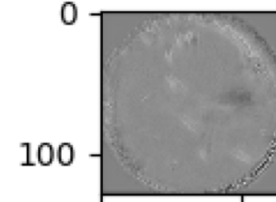
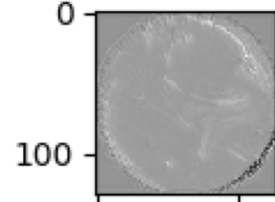
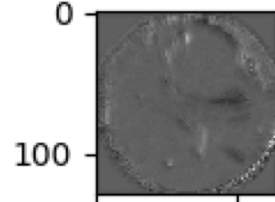
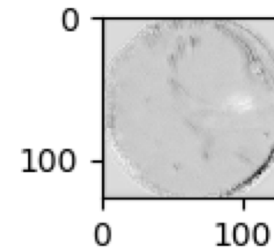
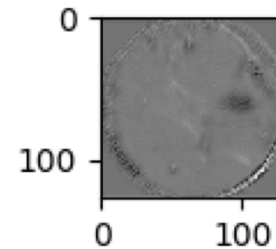
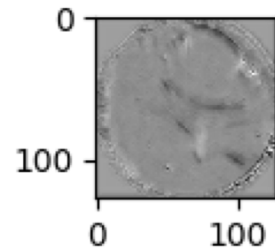
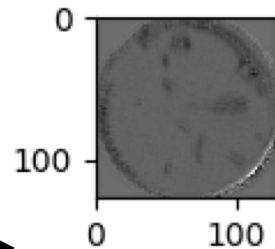
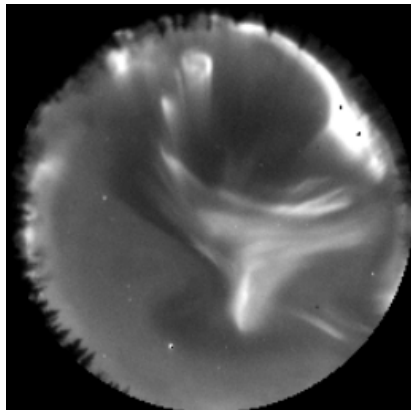
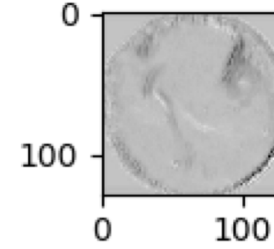
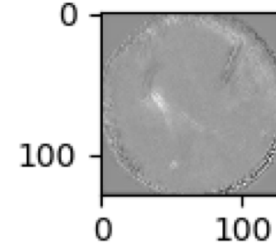
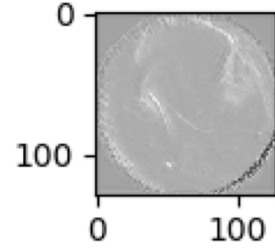
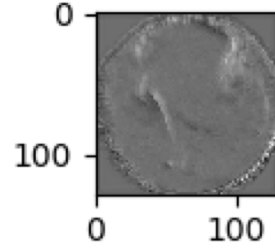
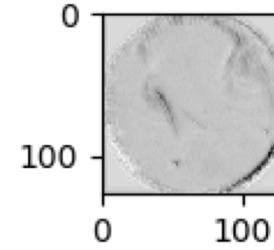
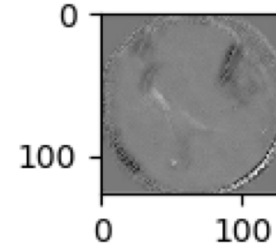
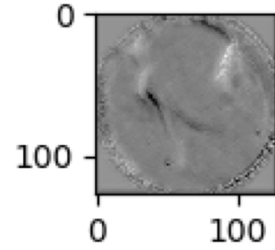
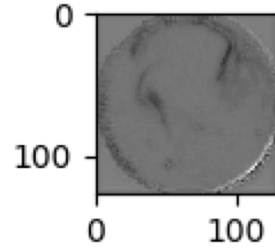
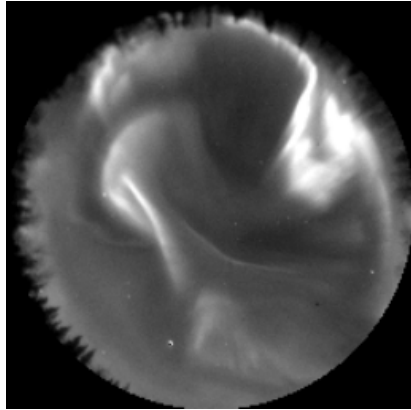


AutoEncoder Analysis

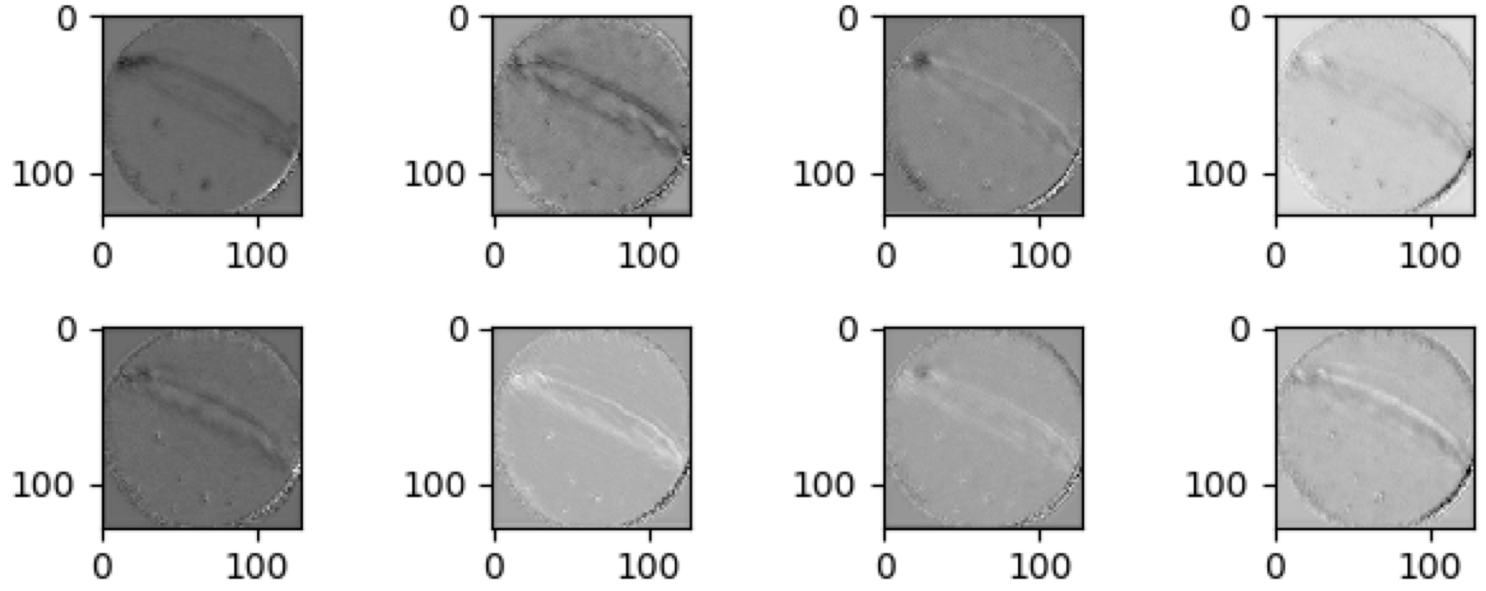
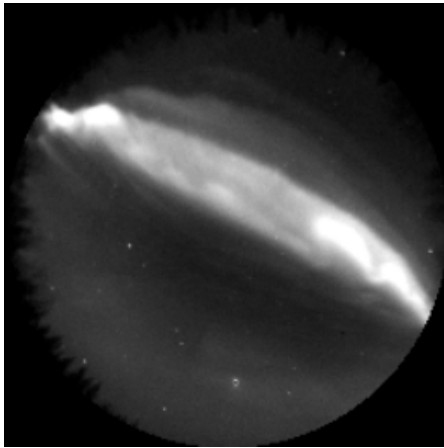


Arc, diffuse, discrete, cloudy, moon, clear/no aurora

Visualization of Feature Maps (Validation)

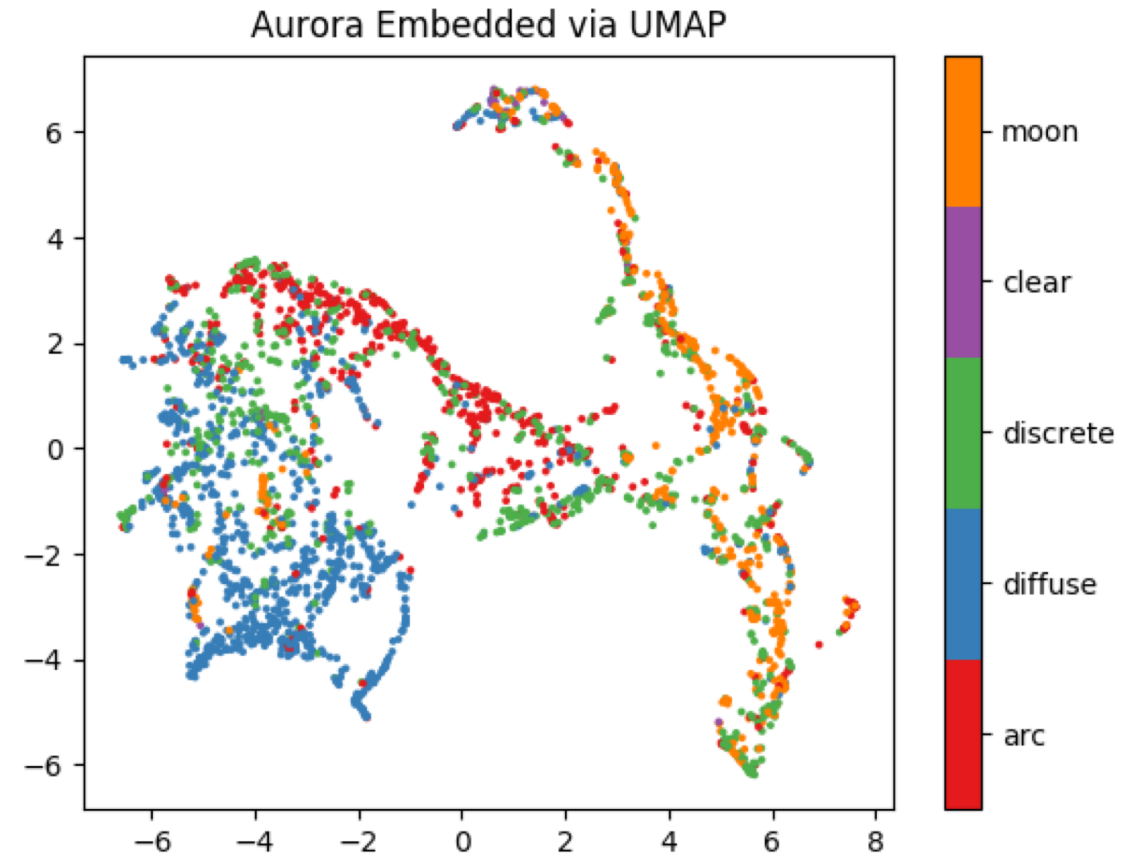
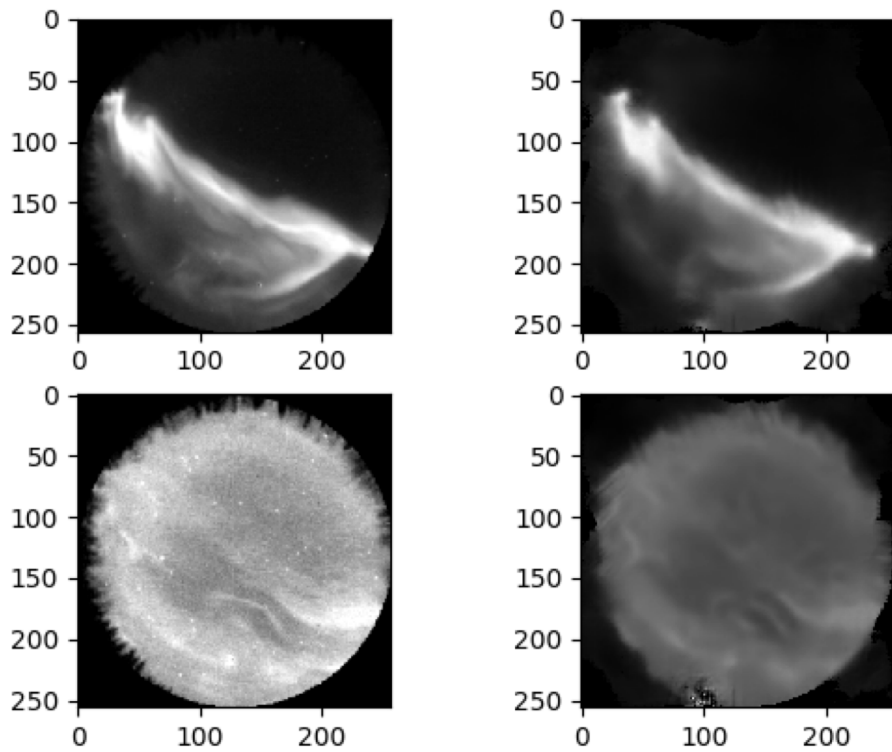


Visualization of Feature Maps (Validation)

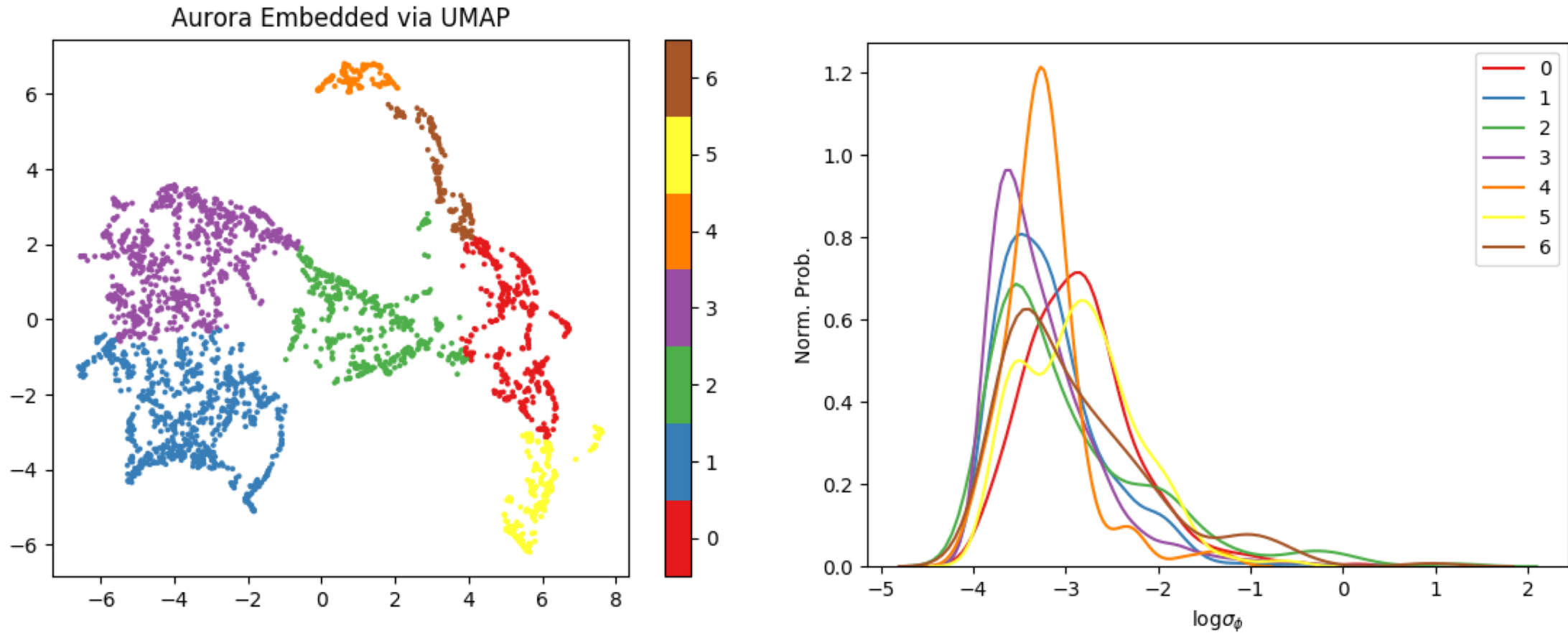


AutoEncoder Analysis - t-SNE

Validation : Visualization of latent space for classified ASI images



Unsupervised Spectral Clustering



Conclusions

- We successfully predict scintillations with TSS = 0.83 using a convolution neural network.
 - Real time performance (50fps)
- Inclusion of auroral images improves model performance
- Bz, Kp, dTEC, Ground Bx, Solar EUV wavelengths He II 303 and Fe IX have high importance in prediction of scintillations.
- We also demonstrate use of residual autoencoder in extracting auroral features and classifying auroral images – Training to be improved by including more images.