Automated Segmentation of the Dayside Aurora from GOLD

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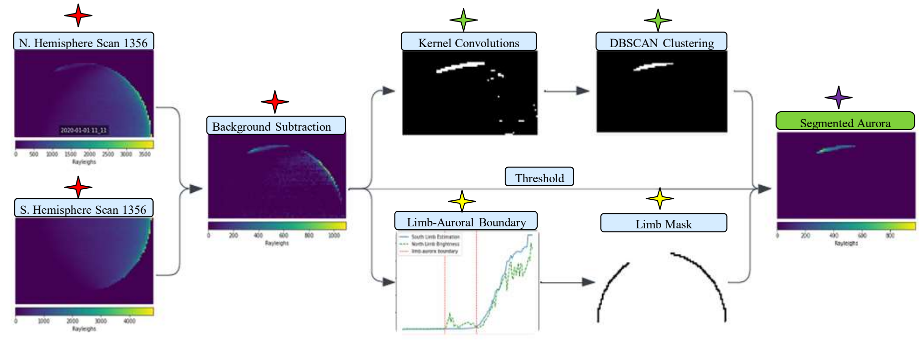
1. Goals and Motivation

Goal: To generate a comprehensive image dataset of the daytime northern aurora using observations from the GOLD mission.

This dataset:
- Provides large-scale snapshots of the aurora, offering orders of magnitude more spatial context than in-situ measurements. This potentially improves our ability to analyze auroral morphology, variability, and offer annotated training data for future machine-learning models.
- Fills in key observational gaps which is poorly observed by specifically targeting observations during daytime conditions.
- Would be the first such dataset produced from GOLD which demonstrates the utility of GOLD's disk-viewing for future investigations of auroral science.

3.0. Classical Segmentation Method

- GOLD is in GEO -> southern scans can be used to model background dayglow, so background subtraction is performed, but it's imperfect…
- Kernels such as Laplacian of Gaussian & Gabor filters are applied to keep the auroral structure as seen from GOLD
- DBSCAN clusters likely auroral pixels from the kernel convolution results.
- A peak-finding algorithm identifies the boundary between auroral emissions and Earth's limb, enabling exclusion of limb pixels from the final mask.
- 50 Rayleigh threshold + binary mask generate final auroral segmentation

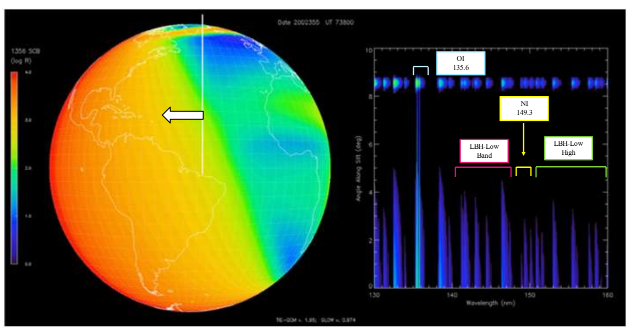


Dataflow for classical segmentation algorithm.

2. GOLD Imager

Position: Geostationary orbit at 47.5° W longitude [1]
Mission Duration: Oct 2018 - Current day (6+ years)

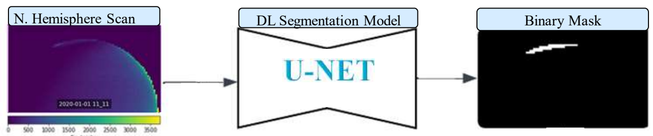
Level 1 Day Dataset Characteristics:
- Imaging spectrograph: Wavelength coverage from 132-162 nm
- Image sampling cadence**:**
  - Early mission phase: ~34 full disk images per day
  - Later mission phase: ~6 full disk images per day
- Image Formation: Full disk images are produced by alternating swaths of the northern and southern hemisphere.



Shown here is an illustration of typical GOLD OI emission data and the swathing direction. On the right is a display of the emission spectrum obtained along the slit. Image courtesy of S. Solomon.

Key Limitations:
- Temporal sampling: 30 minute to 2-hour difference between sequential observations.
- Geometric distortion: Reduced sensitivity at Earth limb regions
- Only signatures of the northern aurora are typically seen.

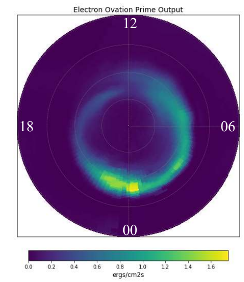
3.1. Deep Learning Method



- Classical algorithm performs well, but depends on hard-coded *magic numbers*, introducing unaccounted errors.
- Deep Learning (DL) models can generalize the binary mask procedure (Figure above) through regularization techniques during training.
- **Trained a U-NET model on 12k+ image-mask pairs generated from the classical method and deployed it to generate the auroral masks for the final dataset production.**

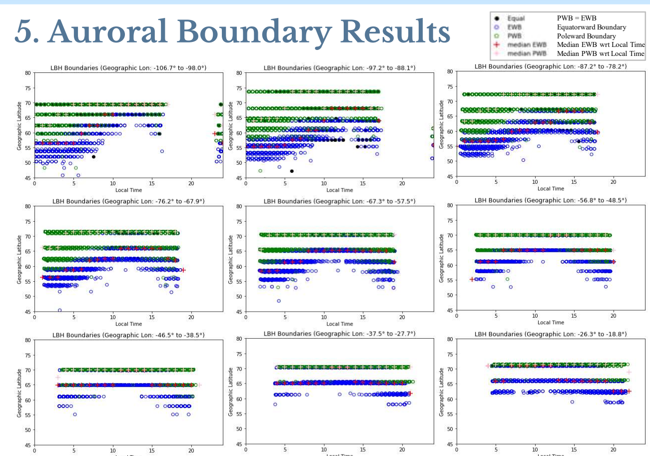
4. Dataset Comparison

- Compared GOLD auroral segmentation against OVATION Prime 2010 (OP) electron flux model, which provides high accuracy under low KP conditions [2,3]
- OP outputs from 2020 will serve as "ground truth"
- Predictions from GOLD are projected into the Quasi-Dipole (QD) magnetic coordinate system.
- **Achieved a Matthew's Correlation Coefficient = 0.76 and Accuracy = 0.89 against OP.**



Electron flux OP output from ISWA data tree.

5. Auroral Boundary Results



Hourly estimated auroral boundaries using DL method. Boundary results span the full year of 2020.

6. Conclusion

An automated segmentation framework was developed to generate the first comprehensive auroral image dataset from the ongoing GOLD mission (6+ years), enabling future auroral science applications.
Two methods were developed:
- **Classical Method:** Combines computer vision, signal processing, and unsupervised learning. While effective, it is prone to errors .
- **Deep Learning Method:** Trained on outputs from the classical method, a DL model (U-NET) learns a more generalized mapping, requiring only northern scans to produce auroral masks.

The DL method performed strongly against OP-labeled data **(MCC = 0.76, Accuracy = 0.89)**, demonstrating its effectiveness at isolating auroral pixels from GOLD observations during **geomagnetically quiet periods.** The results also show the expected diurnal expansion and contraction of auroral boundaries with respect to local time. This indicates the framework's readiness for automatic GOLD data processing in auroral space weather applications.

References:
[1] Eastes, R.W., McClintock, W.E., Burns, A.G. *et al.* The Global-Scale Observations of the Limb and Disk (GOLD) Mission. *Space Sci Rev* 212, 383–408 (2017). https://doi.org/10.1007/s11214-017-0392-2
[2] Newell, P. T., T. Sotirelis, and S. Wing (2010), Seasonal variations in diffuse, monoenergetic, and broadband aurora, *J. Geophys. Res.*, 115, A03216, doi:10.1029/2009JA014805.
[3] Machol, J. L., J. C. Green, R. J. Redmon, R. A. Viereck, and P. T. Newell (2012), Evaluation of OVATION Prime as a forecast model for visible aurorae, *Space Weather*, 10, S03005, doi:10.1029/2011SW000746.