# Development of Software Package Merging THEMIS ASI Images with Total Electron Content and Phase Scintillation Indices

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Outline:

1. The Science
2. Mission Background
3. Software Package Summary
4. Results

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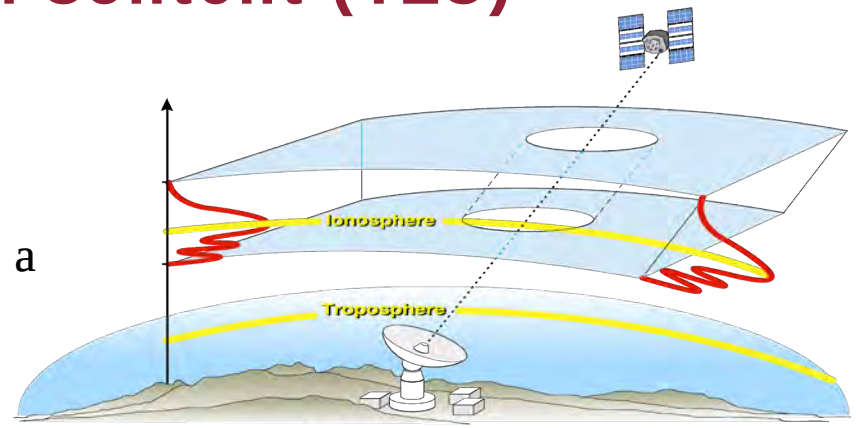
(Spectacular Northwest Territories website)

# The Science: Total Electron Content (TEC)

- Total Electron Content (TEC)
  - Electron density along a path between a receiver and a satellite
  - Units: $10^{16}$ electrons/$m^2$ (1 TECU)




(From Attila Komjathy, JPL)

$$\Delta\phi_{12} = c + \mathrm{b}\int_{L_0(t)}^{L(t)} N_e(z)dz$$

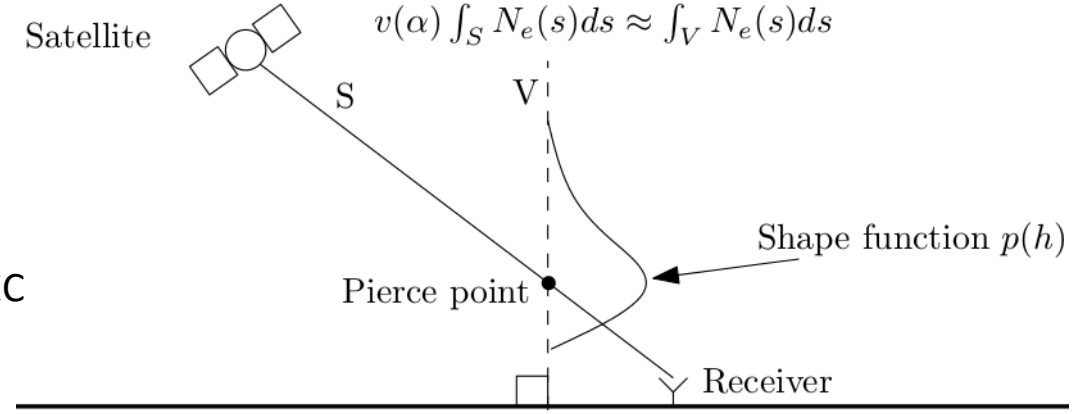
difference in the dual frequency phases

phase ambiguity constant

slant TEC

mapping function

$v(\alpha)\int_S N_e(s)ds \approx \int_V N_e(s)ds$




(From Vierinen et al. 2016)

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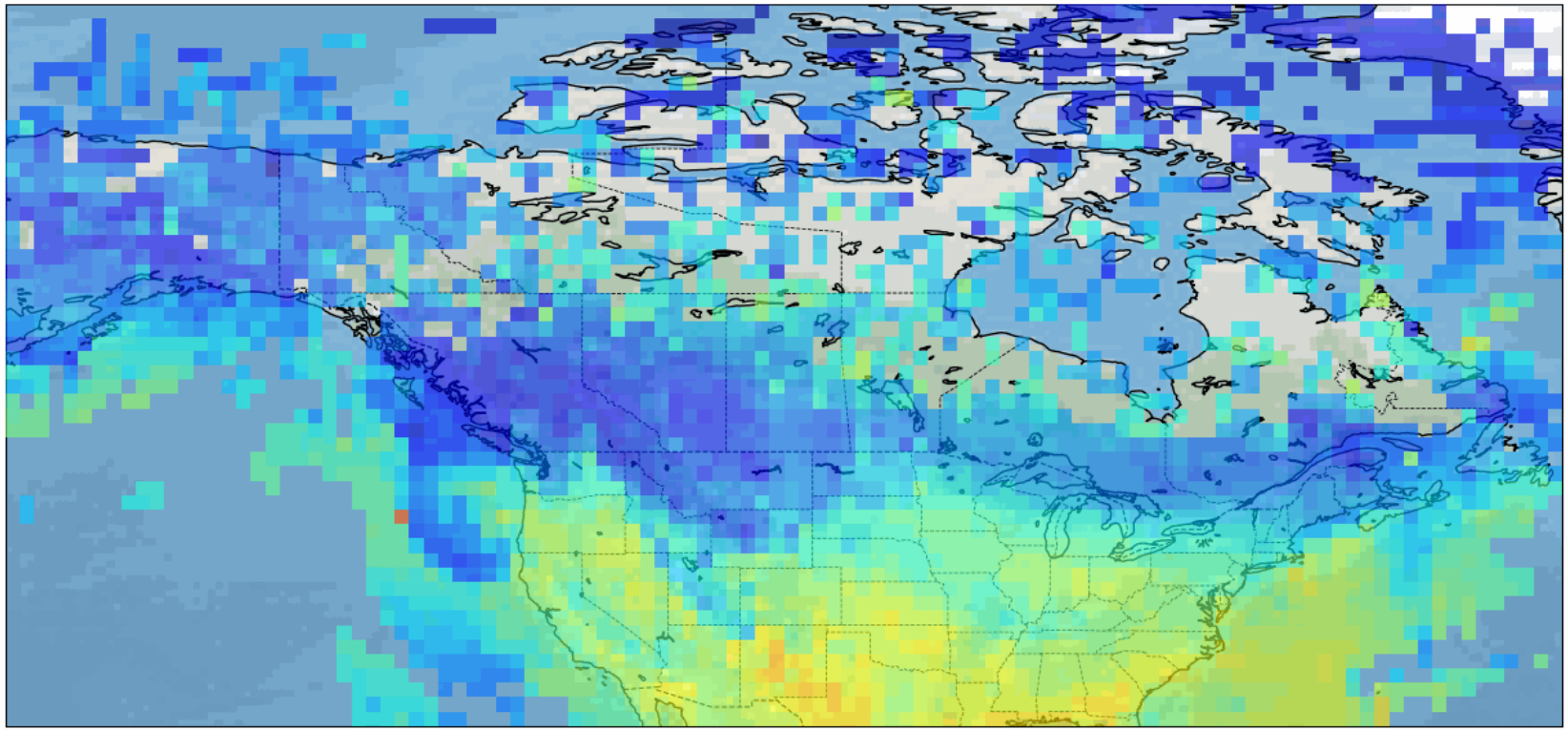


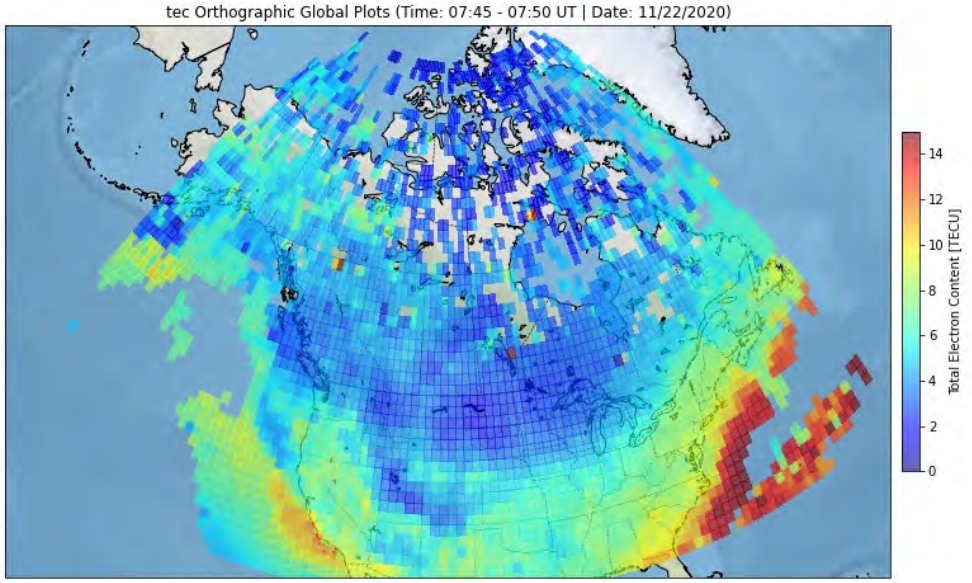


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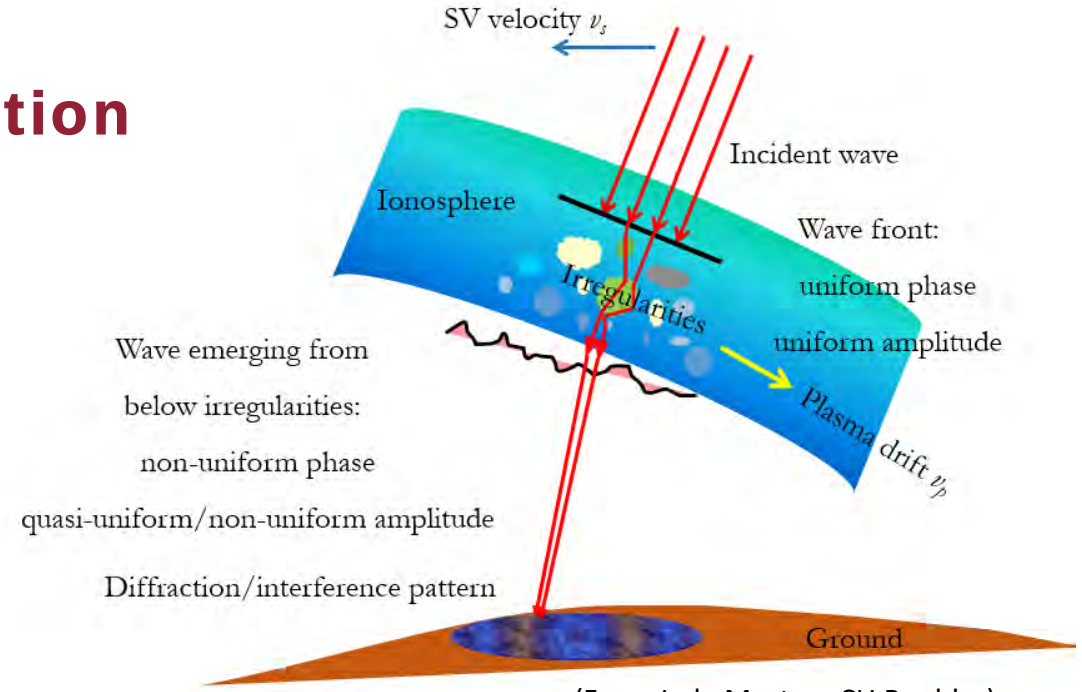
# The Science: Scintillation

- GNSS Phase Scintillation ($\sigma_\phi$)
  - The phase shift of a radio wave as it passes through small-scale irregularities in the ionosphere



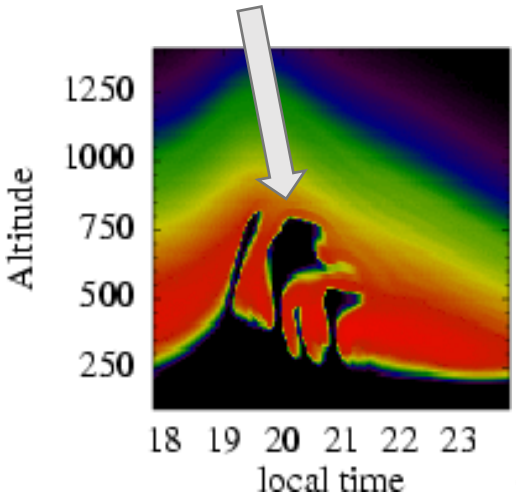

(From Jade Morton, CU Boulder)

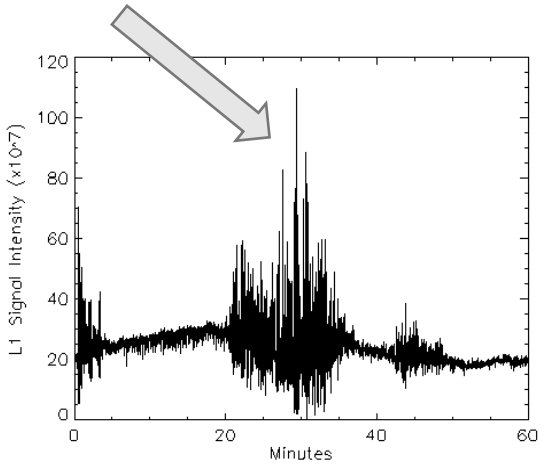
$$\sigma_\phi = \sqrt{\langle \phi^2 \rangle - \langle \phi \rangle^2}$$

standard deviation of the signal phase

irregularity

spike in scintillation




(From Anthea Coster, MIT Haystack)

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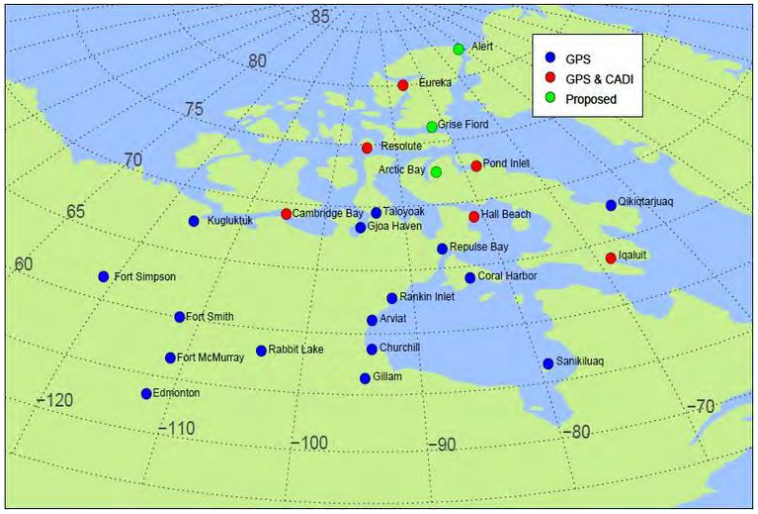
# The MACAWS Project

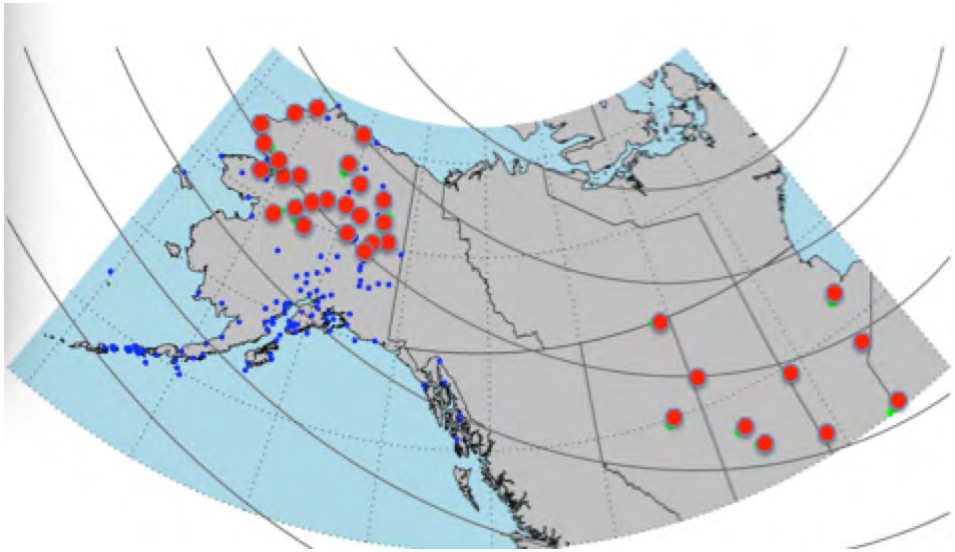
- NSF MRI Collaborative: Development of **M**onitors for **A**laskan and **C**anadian **A**uroral **W**eather in **S**pace
- Collaboration between MIT Haystack Observatory, University of Alaska, University of Calgary, and the **C**anadian **H**igh **A**rctic **I**onospheric **N**etwork (CHAIN)
- 35 receivers in total, not yet fully online
- Goal: To fill in space weather gaps and provide real-time TEC, differential TEC, and scintillation data in high latitude regions

**CHAIN**




(University of New Brunswick)

**MACAWS Network**



(From Anthea Coster, MIT Haystack)

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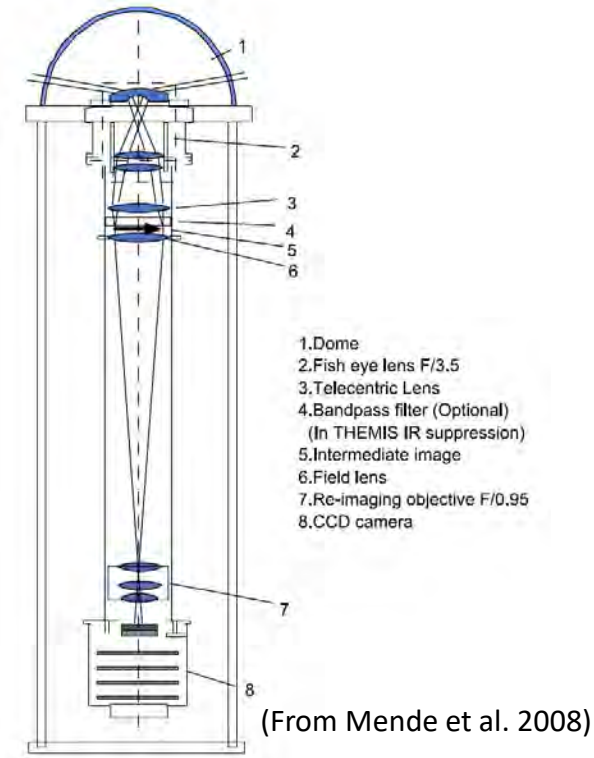
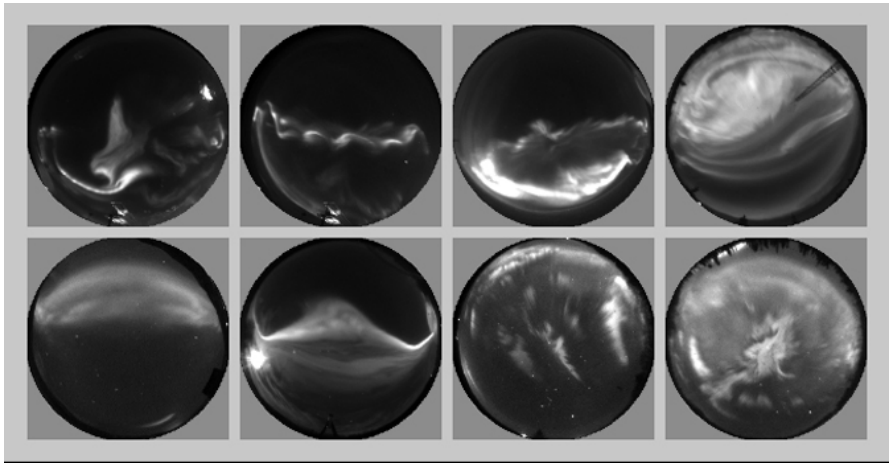
# THEMIS Ground-Based All-Sky Imager (ASI) Array

- **T**ime **H**istory of **E**vents and **M**acroscale **I**nteractions during **S**ubstorms Mission
- A total of 20 All-sky Imagers across Canada and Alaska
- Goal: To observe aurora in the visible spectrum to gain insight into the timing and location of the auroral substorm onset in relation to the events in the magnetosphere.




(From Mende et al. 2008)


(THEMIS, NASA)



(THEMIS, NASA)

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(From Anthea Coster, MIT Haystack)

# Software Package Summary

- Goals:
  1. Data Workflow Improvements
  2. Data Merging Capabilities

GitHub → auroralib

main mit-aurora-reu / auroralib /

| | |
|---|---|
| conradmr98 Edited geographic projection options to animation | |
| .. | |
| animations | Edited geographic projection options to animation |
| plots | Edited geographic projection options to animation |
| tools | Added multiple ASI image plot functionality to ani function |
| _init_.py | Created init .py file for auroralib |

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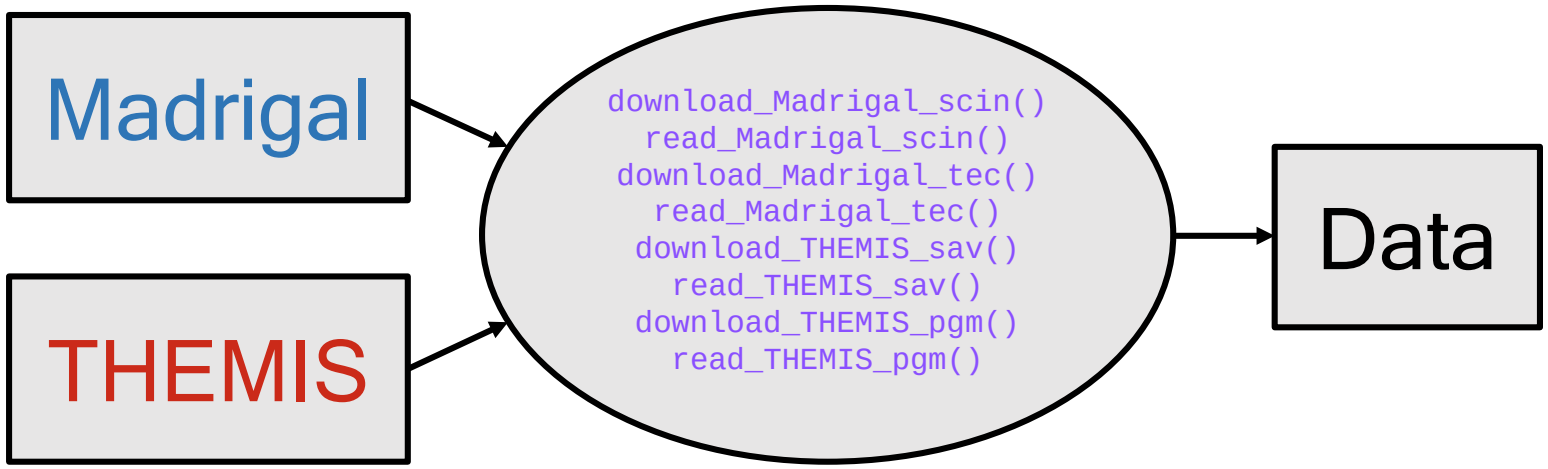
# Data Workflow Improvements

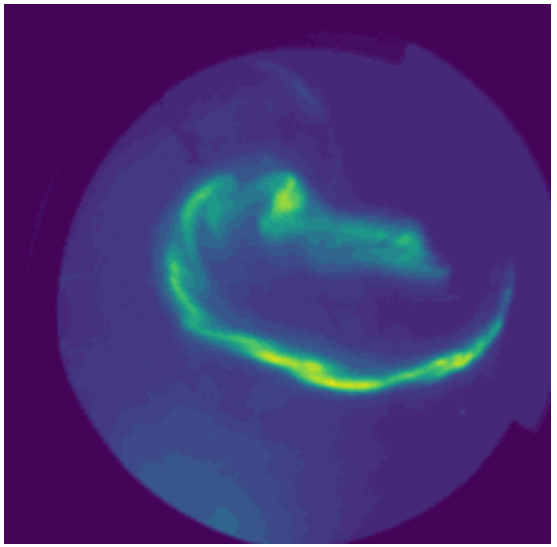
- Created access paths to the Madrigal and THEMIS databases to download TEC, Scintillation, and ASI image data
- Created functionality to read in downloaded data and extract necessary data attributes



# Data Merging Capabilities

- Goal: Merge TEC, Scintillation events, and ASI images
- ASI Image Projection Issues:
  a) pcolormesh_nan function
  b) Masking for elevation angle (commonly used)

Example image file
(256pixel x 256pixel x 20frame)



**Index of /sort_by_project/THEMIS/asi/**

| | | |
|---|---|---|
| ../ | | |
| gaia_plots/ | 01-Nov-2016 21:56 | - |
| rt-mosaic/ | 05-May-2021 16:25 | - |
| skymaps/ | 23-Jan-2020 21:51 | - |
| stream0/ | 18-May-2021 22:43 | - |
| stream0.png/ | 27-May-2020 06:31 | - |
| stream1/ | 01-Jan-2021 00:00 | - |
| stream2/ | 01-Jan-2021 00:00 | - |
| stream3/ | 18-May-2021 23:50 | - |
| stream4.yknf/ | 03-Nov-2008 21:00 | - |

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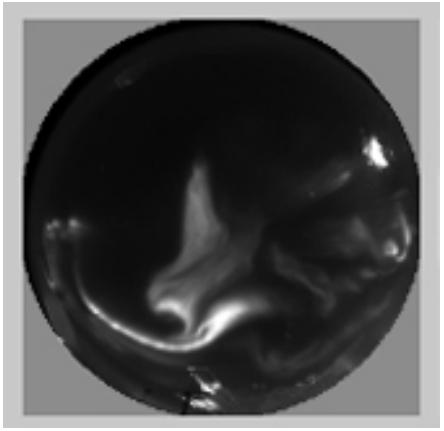
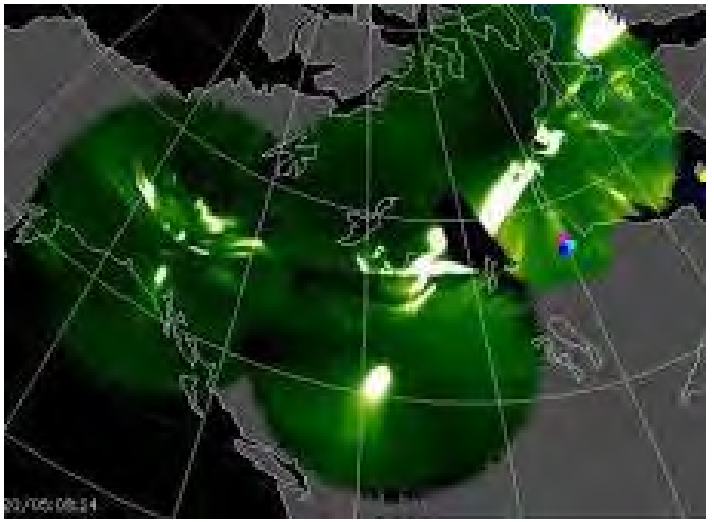
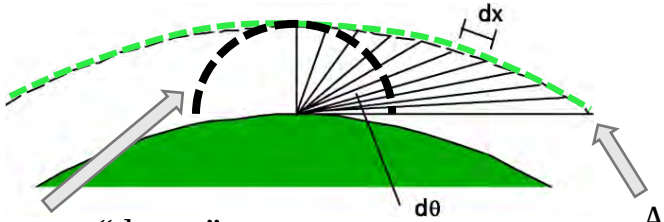


Backwards Projection



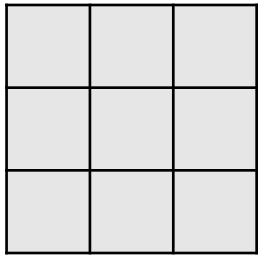
(THEMIS-ARTEMIS)



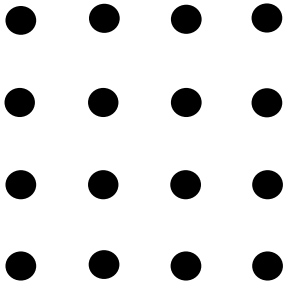

ASI Image "dome"

Aurora Altitude (~110km)

Image File

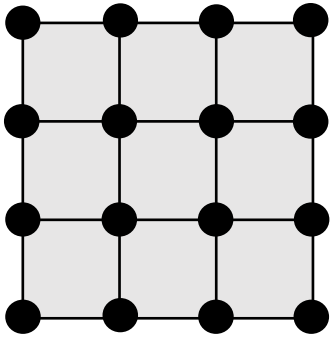


Calibration File



pcolormesh function

Image File + Calibration File



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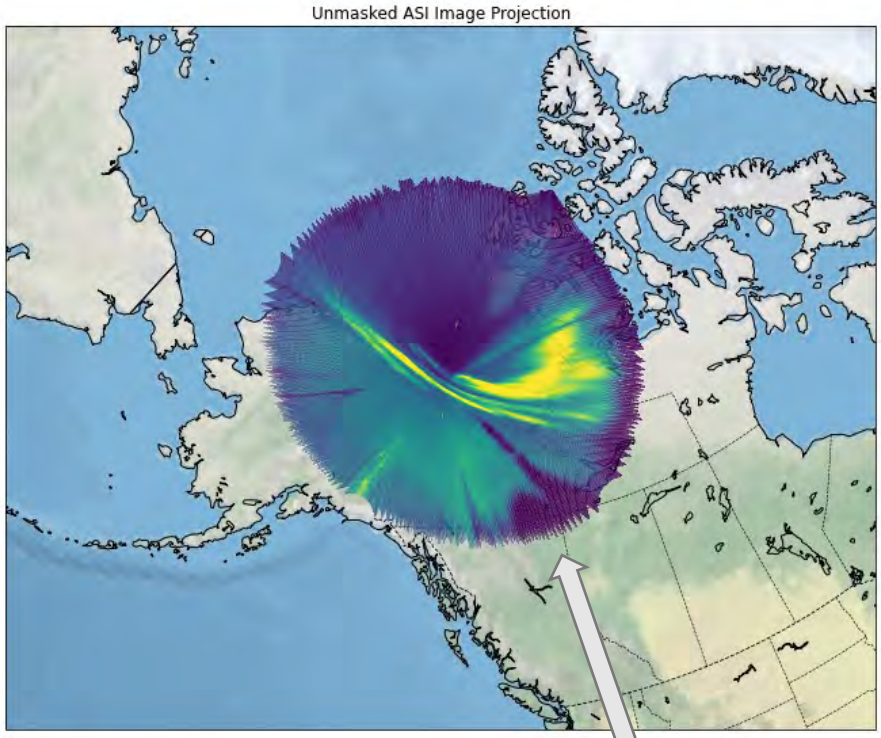
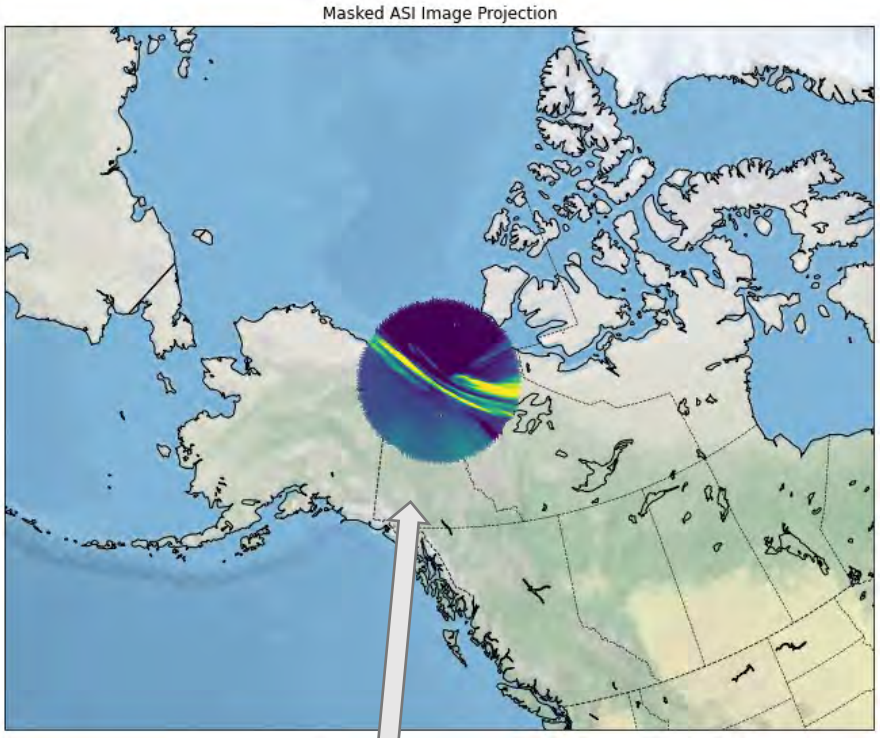
```
# Mask values above an elevation angle of 10 degrees
elevation_lim = 10
elevation_map = cal["FULL_ELEVATION"]
img_scaled[np.ma.masked_invalid(elevation_map).mask] = np.nan
img_scaled[elevation_map < elevation_lim] = np.nan
```

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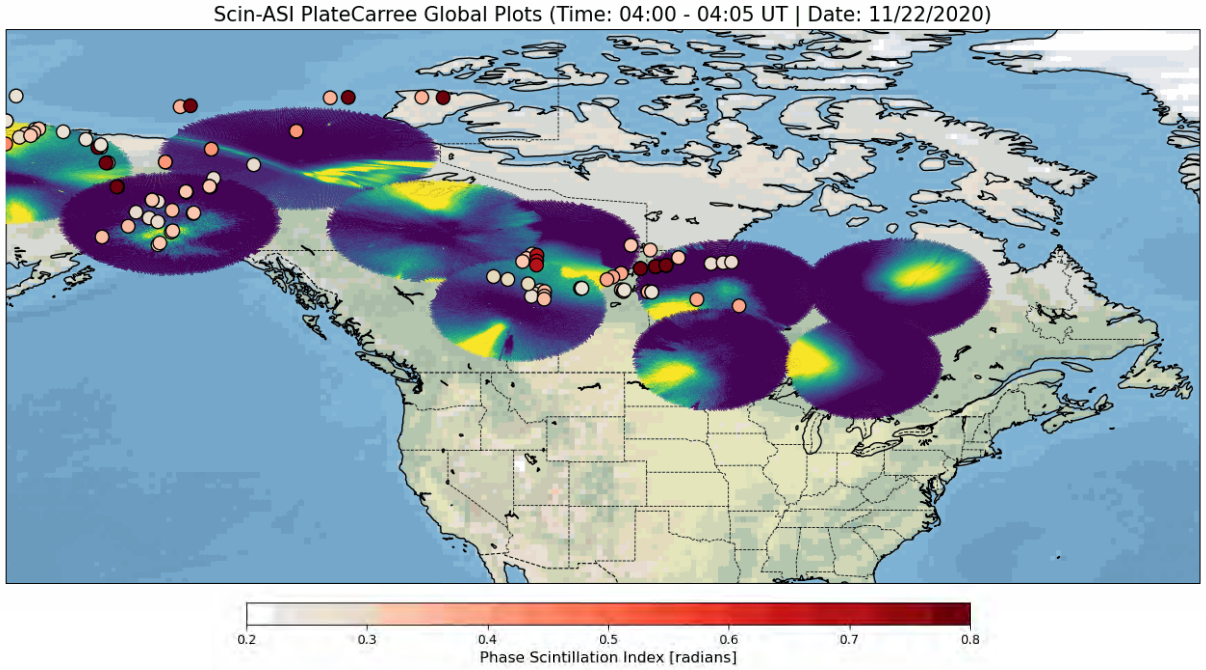
Unmasked Projection

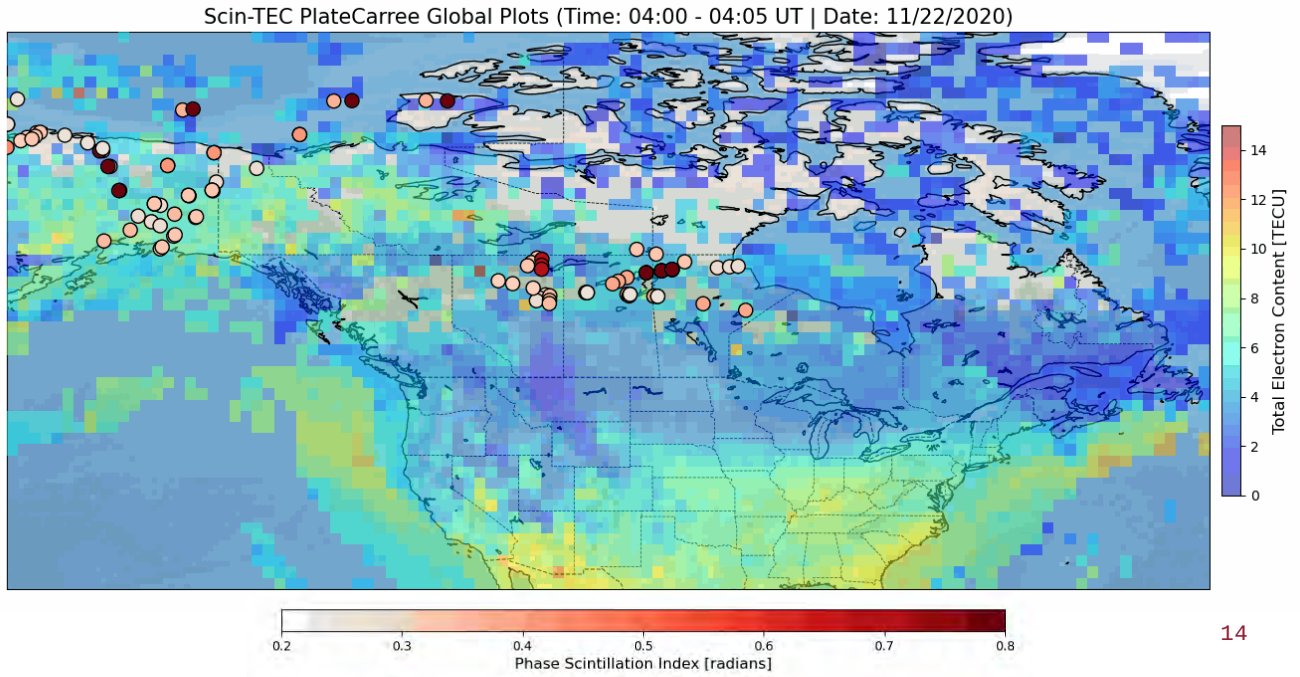
Masked Projection

# Results

- Storm: (Kp = 4)
  November 22, 2020

- Peak Activity: 6-8 UT

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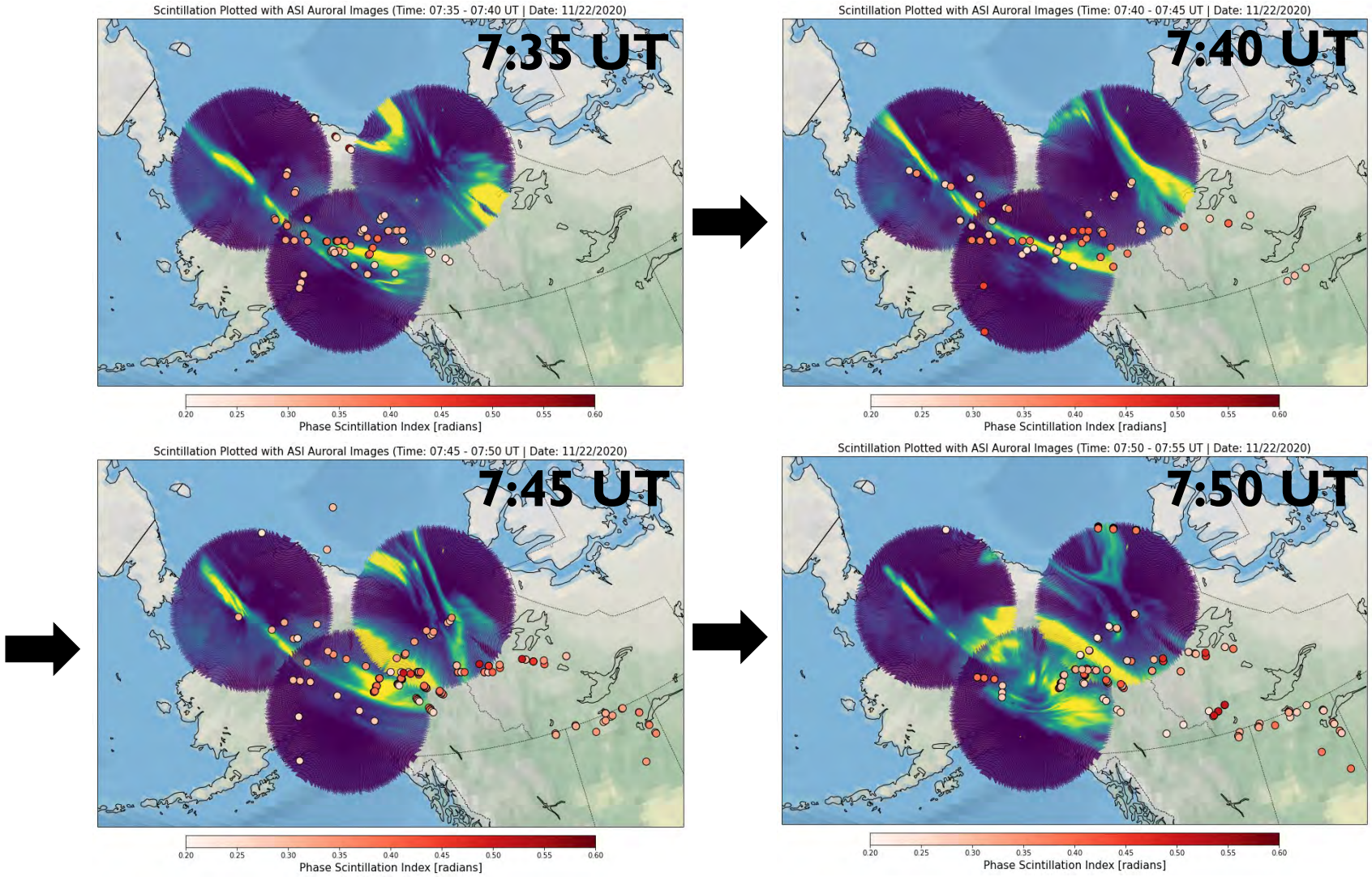
# Results

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So why do we care?

# Acknowledgements


- Thank you:
  - to Anthea Coster and Bill Rideout for guiding me through this program and helping me with any science and programming questions I had
  - to Mike Shumko for helping me with my Github repository development (and referencing code from his aurora-asi-lib)
  - to the MIT Haystack Observatory staff for being welcoming and informative throughout my REU summer internship


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