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
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/m² (1 TECU)

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

- Difference in the dual frequency phases
- Slant TEC
- Phase ambiguity constant

(From Attila Komjathy, JPL)

(mapping function)

(From Vierinen et al. 2016)
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

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

standard deviation of the signal phase

(From Jade Morton, CU Boulder)
The MACAWS Project

- NSF MRI Collaborative: Development of Monitors for Alaskan and Canadian Auroral Weather in Space
- Collaboration between MIT Haystack Observatory, University of Alaska, University of Calgary, and the Canadian High Arctic Ionospheric Network (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
THEMIS Ground-Based All-Sky Imager (ASI) Array

- **Time History of Events and Macroscale Interactions during Substorms 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)

MIT
HAYSTACK OBSERVATORY
Software Package Summary

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

GitHub [auroralib]

```
$ git clone https://github.com/mit-aurora-reu/auroralib
```

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

```python
print(Madrigal)
print(THEMIS)
print(download_Madrigal_scin())
print(read_Madrigal_scin())
print(download_Madrigal_tec())
print(read_Madrigal_tec())
print(download_THEMIS_sav())
print(read_THEMIS_sav())
print(download_THEMIS_pgm())
print(read_THEMIS_pgm())
```
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/

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ASI Image “dome”  

Aurora Altitude (~110km)  

Backwards Projection  

Image File  

Calibration File  

Image File + Calibration File  

pcolormesh function
# 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
Results

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

- Peak Activity: 6-8 UT
Results

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