

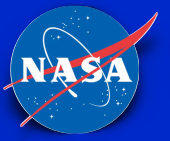


University of  
New Hampshire

# Ground-Based Signatures of Poleward-Moving Auroral Forms

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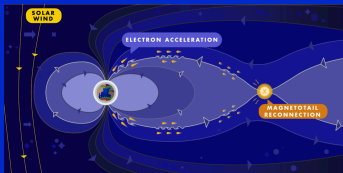


## Introductions:

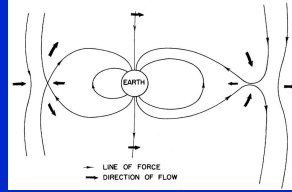
- Poleward-Moving Auroral Forms (PMAFs) have been shown to be Alfvénic auroras generated by dayside magnetic reconnection at the magnetopause. Under B<sub>z</sub> negative conditions this process can occur, sending particles, waves, and energy into the ionosphere.
- On the dayside, Shear Alfvén waves are generated by magnetic reconnection and can be an energy source for auroras [Gurram et. al, 2021]. Alfvén waves have a characteristic signature of field aligned current when measured by in-situ instruments and have been observed during PMAF events by instruments aboard several rockets.
- Shear Alfvén waves cannot accelerate electrons, they are converted into kinetic Alfvén waves which can [Lysak et. al, 2022]
- When the perpendicular wavelength of Alfvén waves becomes comparable to the electron inertial length, parallel electric fields form. [Stasiiewicz et. al, 2000]

$$\omega_{pe} = \sqrt{\frac{n_e e^2}{m_e}}$$

$$\lambda_e = \frac{c}{\omega_{pe}}$$



**Figure 1:** Representation of the motion of Alfvén waves down magnetic field lines on the nightside image credit: Austin Montelius, College of Liberal Arts and Sciences, University of Iowa.



**Figure 2:** Interaction of the solar wind with the Earth's magnetic field [Dungee, 1961]

- Some Alfvén waves are trapped within a resonance cavity, the Ionospheric Alfvén Resonator (IAR) [Knudsen et. al, 1992] due to a cavity where Alfvén speed is abruptly decreased
- Phase mixing within the IAR can explain broadband electron acceleration [Lysak et. al, 2022]
- The interference of Alfvén waves in the cusp region leads to complex patterns in the resulting PMAF events.
- PMAF events prompt ion outflow, which has been shown to be correlated to neutral upwelling
- In this study, we link ground-based induction coil magnetometer signatures to PMAFs, based on the in-situ observations from three rockets.

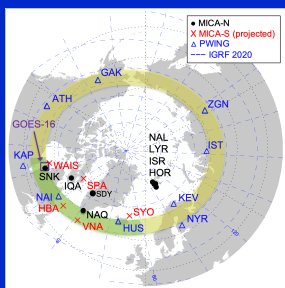
## Data:

- Data was gathered from eighteen different dates on which PMAF events occurred
- On three of these dates rockets were launched into ongoing PMAF events, the CREX 2 (Jan. 18, 2008), RENU 2 (Dec. 13, 2015), and SCIFER 2 (Dec. 21, 2021) missions.
- Instruments aboard the RENU 2 and CREX 2 missions gathered electron data in situ throughout the flight.
- A fluxgate magnetometer aboard RENU2 gathered magnetic field data.
- Data from Induction-coil magnetometers in Longyearbyen, Ny-Alesund, and Hornsund are used to relate wave activity measured on ground to in-situ data.
- We also demonstrate that the ground-based data from the cusp region (Hornsund, Sondrestrom, and Iqaluit) and one in the southern hemisphere (South Pole Station) can be used to estimate the duration of PMAF events on global scales

| Date       |
|------------|
| 01/10/2007 |
| 01/15/2007 |
| 01/17/2007 |
| 01/18/2007 |
| 12/10/2007 |
| 01/18/2008 |
| 12/16/2010 |
| 12/29/2011 |
| 12/17/2012 |
| 12/13/2015 |
| 11/27/2016 |
| 12/18/2017 |
| 12/03/2019 |
| 12/04/2019 |
| 01/03/2020 |
| 11/20/2020 |
| 12/01/2021 |
| 12/13/2021 |

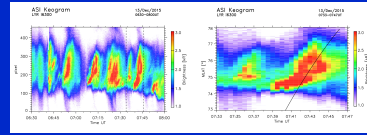
**Figure 3:** List of 18 events considered in this study. On each of these dates, PMAFs occurred overhead and Pi1B waves were observed in induction-coil magnetometer signatures.

## MICA array:

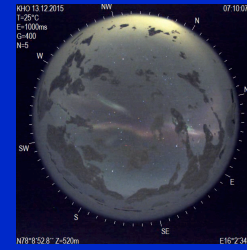


**Figure 4:** The map below shows the Magnetic Induction Coil Array MICA array, where the focus is the highlighted band (in green). Stations with black labels are MICA-North sites. Locations with red labels mark the northern-hemispheric footprints of MICA sites in Antarctica (except that SYO is Japanese site, with good collaborations). This observing capability provides three approximately-conjugate north-south pairs, including HUS-SYO, VNA-NAQ and HBA-NAI. An additional location at SNK (conjugate to GOES-16) results in an interhemispheric array that spans more than ~5 hours in MLT.

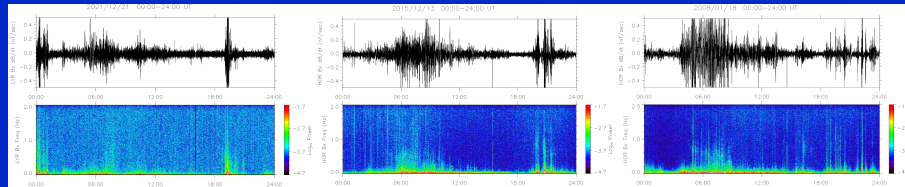
## Data cont.:



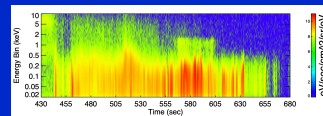
**Figure 5:** The data above is a keogram of an All-Sky camera in Longyearbyen on the date of the RENU2 launch, Dec. 13, 2015. The rocket launched at 7:34:00 UT, during a period of PMAFs.



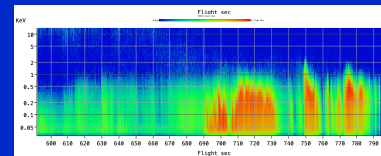
**Figure 6:** All-Sky Camera footage from Dec. 13, 2015, during the launch of RENU3



**Figure 7:** Data collected from an induction-coil magnetometer located in Svalbard on the three rocket launch dates: Jan. 18, 2008; Dec. 13, 2015; and Dec. 21, 2021.

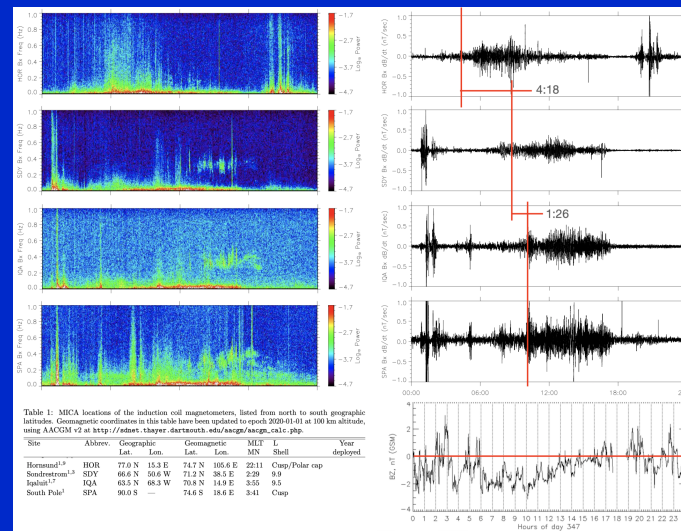


**Figure 8:** Electron Data from RENU 2 flight measuring energy on y-axis and time in seconds on x-axis in the time interval from 430 sec to 680 sec, color indicates intensity

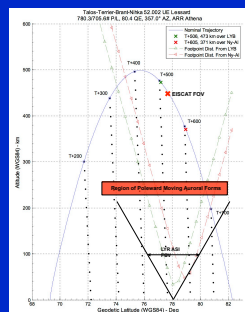


**Figure 9:** Electron Data from CREX 2 flight measuring energy on y-axis and time in seconds on x-axis in the time interval from 600 sec to 800 sec, color indicates intensity

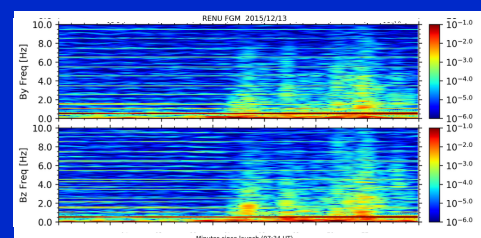
- Data to the right was sourced from Hornsund, Sondrestrom (SDY), Iqaluit (IOA), and south pole (SPA) stations on Dec. 13, 2015. Between 6 am UT and about 16 UT, B<sub>z</sub> conditions of the IMF were consistently negative, measured by the ACE satellite.
- As time progresses, the Earth turns, and three different stations at the same latitude passed through the cusp, as well as a south pole station
- The measurements from South Pole Station, along the conjugate field line connected to Sondrestrom are presented below.



**Figure 10:** The data above shows the wave activity measured at four different stations during B<sub>z</sub> negative conditions. The top four graphs in the left and right columns indicate measurements of wave activity by induction-coil magnetometers at the Hornsund, SDY, Iqaluit, and SPA stations on Dec. 13, 2015. The vertical red lines in first four graphs in the right column indicate position in the cusp in magnetic local time (MLT) as noted by the table in the bottom left. The graph in the bottom right indicates the B<sub>z</sub> component of solar wind over time on the date. The red line is placed at 0 to divide positive and negative.



**Figure 11:** Trajectory of the RENU2 rocket, altitude is plotted against latitude, with the time marked at intervals along the trajectory. Field of view of the All-Sky Camera is included, as well as magnetic field lines and the region of PMAFs.



**Figure 12:** Data from the fluxgate magnetometer aboard RENU2. Frequency is graphed against time, power spectral density is indicated by color. [Kim]

## Results:

### RENU2, CREX 2, and SCIFER 2 launch results:

- On each flight date, wave disturbances were observed which lasted through the duration of the PMAF event.
- Rocket data confirmed that the waves were Alfvénic on the three flight dates, since the electrons were observed to be traveling in the field-aligned direction.
- Wave signatures were Pi1B waves.

### December 13, 2015 event:

- On Dec. 13, 2015, negative B<sub>z</sub> conditions continued for 10 hours, with PMAFs being visible in Longyearbyen starting before 07:00 UT. Magnetometers located near the same magnetic latitude (i.e., the cusp region) scanned the event. As each station came to face the sun due to the rotation of the Earth, the magnetometers registered PMAF wave activity near the same approximate MLT, with each magnetometer providing similar readings when facing the sun.
- The observations show that nearly identical PMAF signatures also occurred in the southern hemisphere, at South Pole Station (nearly conjugate to Iqaluit). The levels of activity at all sites is comparable.
- Data from the fluxgate magnetometer aboard RENU3 confirm the results seen in the ground based induction-coil magnetometer.
- Signals from the ground-based magnetometers are expected to be more spread out than the fluxgate magnetometer aboard RENU3 due to ducting in the atmosphere.
- This event provides evidence for our understanding of the magnetometer response to PMAF events. It also demonstrates the capability for placing the observations in a global context. For example, the set of observations show that this particular PMAF event persisted for at least 10 hours — presumably driving ion outflow and neutral upwelling the entire time.

## Conclusions:

- This poster shows ground and space-based observations of PMAFs, identifying a classic Pi1B signature for these events. That same signature is then used to estimate the global extent of PMAF effects, presumably including ion outflow and neutral upwelling. We summarize as follows:
- Sounding rocket observations of 3 PMAF events were compared to ground-based magnetometer data in order to identify their ground-based signature. We determine that the Alfvén waves that drive the aurora produce the ground-based signatures of PMAFs. The implication is that a network of ground-based magnetometers support indirect observations of PMAFs.
  - Extending the ground-based observations to include data from other sites near "cusp latitudes", we find that the PMAF persisted for at least 10 hours. Noting that PMAFs have been strongly linked to ion upflow and neutral upwelling, a reasonable conclusion is that this event provided 10 hours of both processes.
  - Taking this work one step further, we also show (though only at a single station) comparable and simultaneous observations in the southern hemisphere

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## Acknowledgements:

This material is based upon work supported by the National Aeronautics and Space Administration under Grant/Contract/Agreements 80NSSC21K0972, 80NSSC18K0923 and NNX08AQ27G. The work is also supported by the National Science Foundation awards 2133897 and 2332428.