A Study of Southern Hemisphere Poleward Moving Radar Auroral Forms

Aidan Thayer, William Bristow
The Pennsylvania State University

Introduction

Flux transfer events, or FTEs, open a window between the solar wind and the Earth's magnetosphere and in the process accelerate magnetospheric plasma around the magnetopause[8]. FTEs are observed through the signature of this acceleration at the ionospheric footprint of the magnetic field lines connecting to the magnetopause, and the production of dayside, repetitive, auroral arcs near both magnetic poles, which are categorized as polar moving auroral forms, a specific and common hallmark of FTEs[3]. These poleward moving auroral forms, or PMAFs, last on average only 5 minutes and can move as fast as a kilometer per second, meaning very high temporal and spatial resolution is required to discern their convection features[2].

A potential marker for PMAFs are poleward moving radar auroral forms, or PMRAFs, arcs which are observed through radar and believed to be the radar signature of PMAFs but may lack the accompanying optical measurements to serve as confirmation of aurora. In the Northern Hemisphere, there is enough supporting instrumentation that PMAFs and PMRAFs can be observed simultaneously, but in the Southern Hemisphere the lack of ground-based imagers over the oceans requires assuming PMRAFs are associated with their optical counterpart without confirmation. The primary instruments measuring PMRAFs continuously at polar latitudes in the Southern Hemisphere are the high frequency radar arrays that make up the Super Dual Auroral Radar Network, or SuperDARN. SuperDARN measures line-of-sight plasma velocity of the ionosphere using a network of phased-array radars.

We present here a summary of southern-hemisphere PMRAFs throughout 2021, with a few specific examples included to highlight convection patterns through McMurdo and South Pole stations (Figure 3). We were especially interested in PMRAFs that we could detect at both stations, tracking the flow from one station to another.

Methodology

To identify potential PMRAFs from SuperDARN data, we started with 24-hour summary plots at the South Pole station of the range of the observed plasma velocity or return power vs the time of day. We used these graphs to observe the speed of the plasma from the color, as seen in the legend in Figure 2, generally varying from -1 km to 1 kilometer per second. By reviewing the previous literature on PMAFs, we determined likely candidates for PMRAFs would[4,6,7]:

- Occur near local magnetic noon (1600 UTC)
- Clearly be heading towards or away from the pole
- Occur sequentially
- Have a period of shorter than ten minutes

With these characteristics in mind, we identified 60 potential candidates PMRAFs over the course of 2021. To check for statistical significance of various parameters, we pulled auroral indices and the interplanetary magnetic field values from SuperMAG and OMNI, respectively, as seen in Figure 3 and plotted them on histograms. We then cross-checked these timestamps with events at McMurdo station, looking for 'streaks' of plasma heading into the throat of the radar indicative of a PMRAF heading towards the pole.

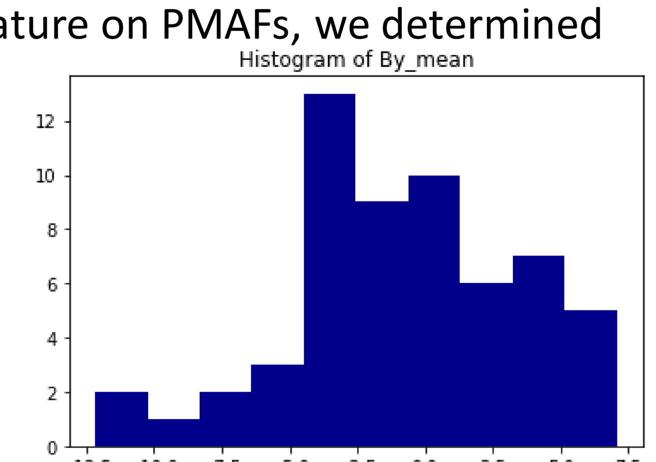

Fig. 1. Histogram of PMRAF By pulled from OMNI throughout 2021

We then examined the convective flow field determined by combining observations from all the southern-hemisphere SuperDARN radars, as seen in Figure 4[2]. As an example, see the data from 3/21/2021 provided with minute time stamps.

Results

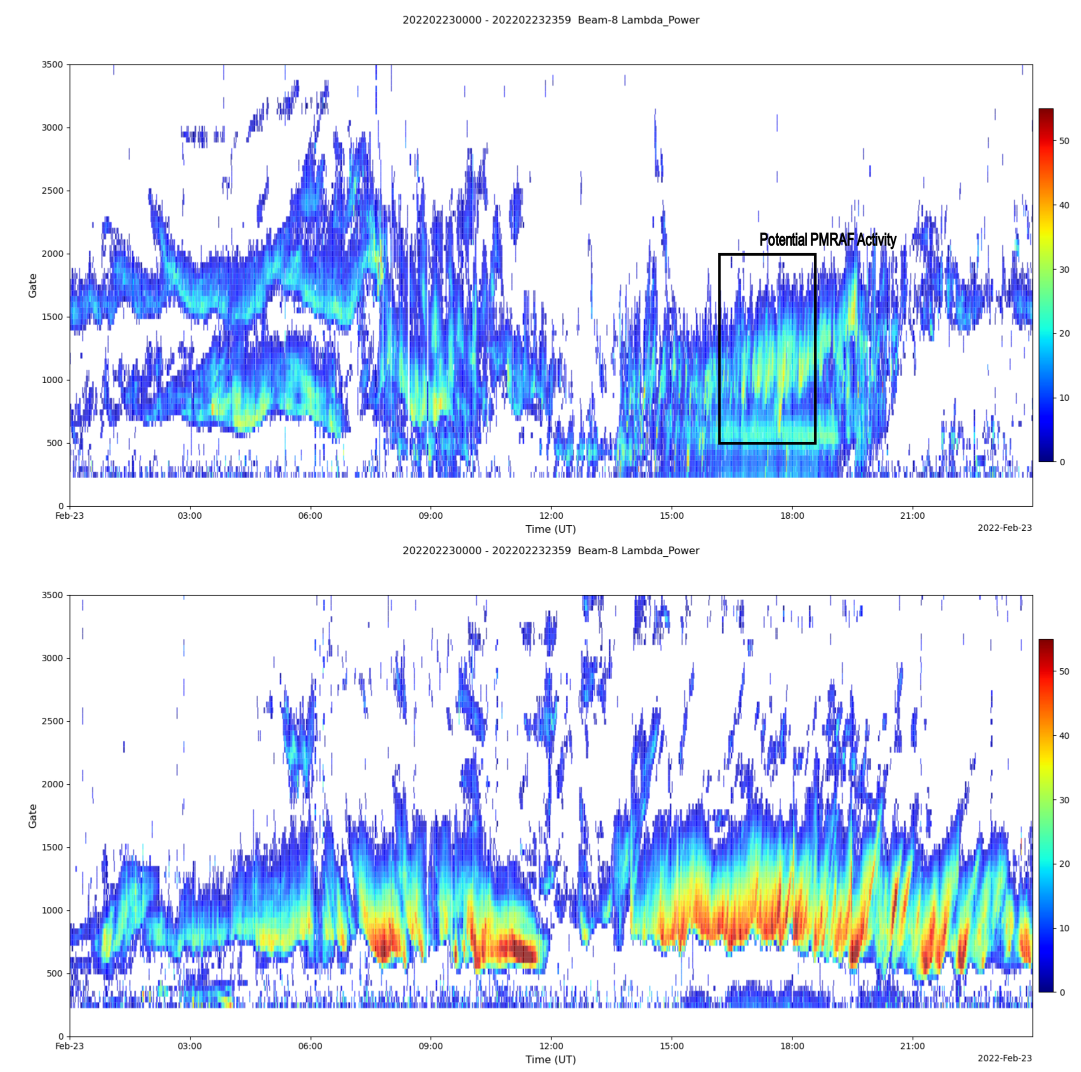

Fig. 2. Range time intensity plot of 2/22/2022, both South Pole and McMurdo Stations. Red indicates high reflectivity; blue is low reflectivity

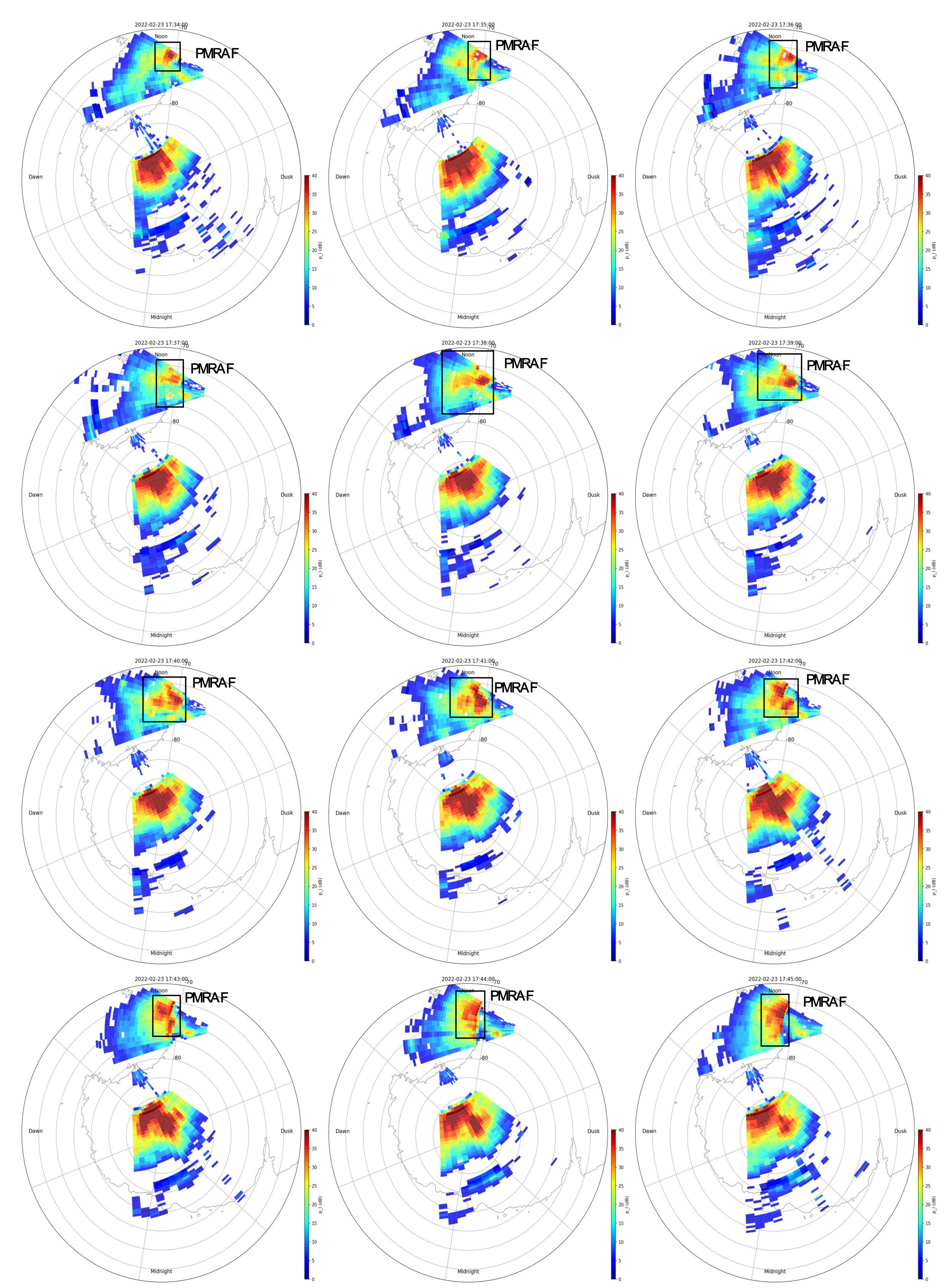

Fig. 3. Tracking a PMRAF at South Poke Station on 2/23/2022, 1900 UTC. Note the feature in red

Results (cont.)

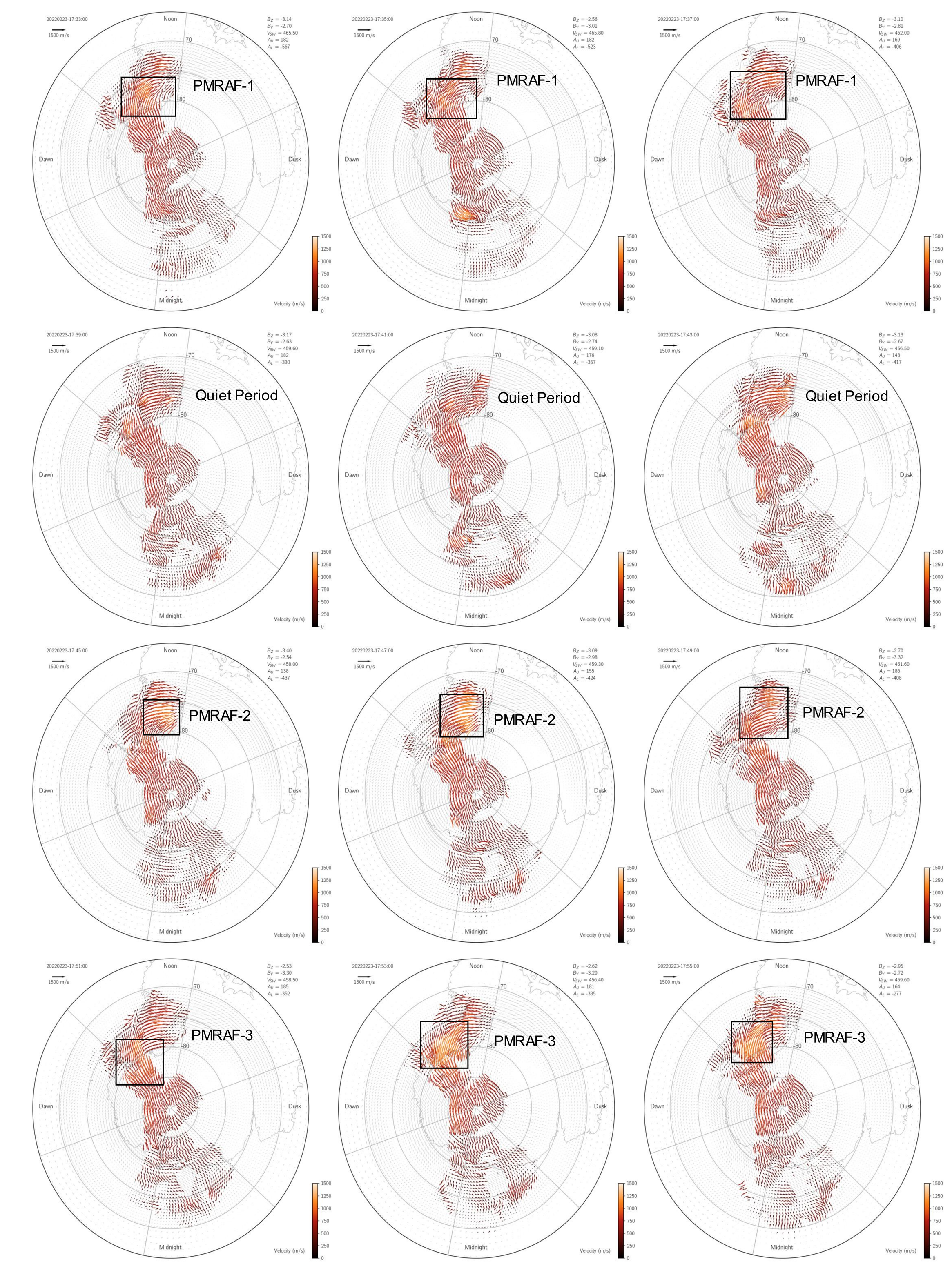

Fig. 4. Convection map of all southern-hemisphere SuperDARN radars.

Discussion and Future Work

We have left the solar minimum as of 2023, meaning that there will likely be far more than 60 days with PMRAFs in 2022 and 2023. Rather than arduously expanding this study by hand, we hope to find a method to automatically identify PMRAFs from radar data, perhaps using a similar arciness index as described in Goertz et al[4]. We are also interested in investigating Joule Heating due to PMRAFs and their impact on the density of the upper atmosphere, as previous studies have shown a potential effect from PMAFs on signal lock on low earth orbiting satellites[5]. It is also important to discover, perhaps using data from the Northern Hemisphere's extensive optical instruments, the true extent of the correlation between PMRAFs and PMAFs.

Works Cited

1- Bristow, W. A. (2019). Application of RADAR imaging analysis to SuperDARN observations. *Radio Science*, 54, 692–703.
2- Bristow, W. A., Lyons, L. R., Nishimura, Y., Shepherd, S. G., & Donovan, E. F. (2022). High-latitude plasma convection based on SuperDARN observations and the locally divergence free criterion. Journal of Geophysical Research: Space Physics, 127, e2022JA030883. https://doi.org/10.1029/2022JA030883
2- Fasel, G. J. (1995), Dayside poleward moving auroral forms: A statistical study, *J. Geophys. Res.*, 100(A7), 11891–11905
3- Frey, H.U., Han, D., Kataoka, R. *et al.* Dayside Aurora. *Space Sci Rev* **215,** 51 (2019).
4- Goertz, A., Partamies, N., Whiter, D., and Baddeley, L.: Morphological evolution and spatial profile changes of poleward moving auroral forms, Ann. Geophys., 41, 115–128, https://doi.org/10.5194/angeo-41-115-2023, 2023.
4- Greenwald, R.A., Baker, K.B., Dudeney, J.R. *et al.* DARN/SuperDARN. *Space Sci Rev* **71,** 761–796 (1995).
5- Oksavik, K., van der Meeren, C., Lorentzen, D. A., Baddeley, L. J., and Moen, J. (2015), Scintillation and loss of signal lock from poleward moving auroral forms in the cusp ionosphere, *J. Geophys. Res. Space Physics*, 120, 9161–9175, doi:10.1002/2015JA021528.
6- Sandholt, P. E., Denig, W. F., Farrugia, C. J., Lybekk, B., and Trondsen, E., Auroral structure at the cusp equatorward boundary: Relationship with the electron edge of low-latitude boundary layer precipitation, *J. Geophys. Res.*, 107(A9), 1235, 2002.
7- Sandholt, P. E. and Farrugia, C. J., Poleward moving auroral forms (PMAFs) revisited: responses of aurorae, plasma convection and Birkeland currents in the pre- and postnoon sectors under positive and negative IMF B_y conditions: Ann. Geophys., 25, 1629–1652, 2007.
8- Southwood, D. J., Farrugia, C. J., and Saunders, M. A. (1988). What are flux transfer events? *Planetary and Space Science*, 36(5), 503–508.