SWARM IN SITU OBSERVATIONS OF F-REGION POLAR CAP PATCHES CREATED BY CUSP PRECIPITATION

L. GOODWIN,1 * B. ISERHRIENH,1 D. M. MILES,2 S. PATRA,3 C. VAN DER MEEREN,1 S. C. BUCHERT,5 J. BURCHILL,6 L. B. N. CLAUSEN,3 D. J. KNUDSEN,9 K. A. M. WILLIAMS,1 AND J. MOEN3
(1) INSTITUTE OF SPACE AND ATMOSPHERIC STUDIES, DEPARTMENT OF PHYSICS AND ENGINEERING PHYSICS, UNIVERSITY OF SASKATCHEWAN, SASKATOON, SASKATCHEWAN, CANADA. (2) DEPARTMENT OF PHYSICS, UNIVERSITY OF ALBERTA, EDMONTON, ALBERTA, CANADA. (3) DEPARTMENT OF PHYSICS, UNIVERSITY OF OSLO, NORWAY. (4) BIRKELAND CENTRE FOR SPACE SCIENCE, DEPARTMENT OF PHYSICS AND TECHNOLOGY, UNIVERSITY OF BERGEN, NORWAY. (5) SWEDISH INSTITUTE OF SPACE PHYSICS, UPSALA, SWEDEN. (6) DEPARTMENT OF PHYSICS AND ASTRONOMY, UNIVERSITY OF CALGARY, CALGARY, ALBERTA, CANADA.

*Email: Lindsaygoodw@gmail.com, Phone: +1 (306)-966-1239

ABSTRACT

High-resolution in situ measurements from the three SWARM spacecraft, in a string-of-pearls configuration, provide new insights about the combined role of flow channel events and particle impact ionization in creating F-region electron density structures in the northern Scandinavian dayside cusp. We present a case of polar cap patch formation where a reconnection-driven low-density relative westward flow channel is eroding the dayside solar-ionized plasma but where particle impact ionization in the cusp dominates the initial plasma structuring. In the cusp, density features are observed which are twice as dense as the solar-ionized background. These features then follow the polar cap convection and become less structured and lower in amplitude. These are the first in situ observations tracking polar cap patch evolution from creation by plasma transport and enhancement by cusp precipitation, through entrainment in the polar cap flow and relaxation into smooth patches as they approach the nightside auroral oval.

OBSERVATIONS

The SWARM spacecraft traveled in a string-of-pearls configuration with SWARM B leading, SWARM A in the middle, and SWARM C trailing. During three successive noon-midnight passes on 30 December 2013 the Interplanetary Magnetic Field (IMF) $B_z$ is consistently southward and the IMF $B_y$ is consistently positive, suggesting active dayside reconnection.

Figure 1 shows the trajectory of the spacecraft during the third pass. At the location of SWARM B optical emissions (Figure 1a) are collocated with high frequency radar backscatter (Figure 1b), identifying the cusp [4]. A notable electron density ($N_e$) depletion just before 9:42 Universal Time (UT) (Figure 1c) coincident with an approximate 2 km/s westward deflection in the relative ion flow ($V_e$). The shaded area identifies a region with active cusp electron precipitation, inferred from a structured electron temperature (Figure 1e), structured $N_e$ structured eastward (cross-track) magnetic perturbations (Figure 1f) [3], and optical emissions.

Figures 2a–c show the $N_e$ profiles of the three passes as a function of along-track distance from 60° geomagnetic latitude. In all three passes, all spacecraft observe a distinct depletion in $N_e$ in the equatorward portion of the cusp. This depletion is seen at a lower magnetic latitude with each pass. The $N_e$ depletion region is nearly constant for the nine spacecraft passes and matches the baseline $N_e$ observed deep in the polar cap. Poleward of the depletion region, while still in the cusp precipitation region, all spacecraft passes encountered an increased and highly structured $N_e$. This technique provides more context and can resolve shorter time-scale changes than previous in situ observations (e.g., [5]).

Figure 2: The measured $N_e$ from all three spacecraft and all three passes from 30 December 2013 shown as a function of along-track distance from 60° Altitude Adjusted Corrected Geomagnetic Latitude [1]. (a) 09:42 UT. (b) 08:05 UT. (c) 09:40 UT.

PLASMA SOURCES, MIXING, AND PATCHES

The $N_e$ depletion and relative westward $V_e$ channel are consistent with a positive IMF $B_y$, generating a $N_e$ minimum from low-$N_e$ plasma being transported westward into the cusp from the postnoon sector [3]. This $V_e$ channel prevents the direct injection of Extreme Ultra-Violet (EUV) plasma into higher latitudes, but erodes regions of EUV plasma as it moves equatorward, mixing them with low-$N_e$ plasma from the overall polar cap convection pattern.

Figure 3 identifies eight enhanced $N_e$ “features” from Figure 2b.

- Features I–VIII show an along-track motion consistent with traveling parallel to the streamlines of convection.
- $N_e$ features that are closer to the region of particle impact ionization are more structured than those further along-track, which are evolving into the classic density profile (asymmetric and flat-topped shape) of a polar cap patch.
- In the region of features I–III, an overall $N_e$ increase indicates the dominant role particle impact ionization can have in producing $N_e$ structures on top of either EUV ionized plasma that has been transported into the polar cap or the background $N_e$ of the polar cap.
- These observations contrast the classical view of patch formation, in which EUV ionized patches are chopped off the Tongue of Ionization (TOI) and structure is added by the Gradient Drift Instability (GDI) [2].

Figure 3: Observations from 30 December 2013. A magnified view of Figure 2b showing the along-track (poleward) motion of $N_e$ structures. Features encountered in sequence by SWARM B (red), SWARM A (green), and SWARM C (blue) indicate along-track (poleward) motion. Shaded regions I–VIII identify “features”.

CONCLUSIONS AND FUTURE WORK

1. A reconnection driven relative westward $V_e$ channel and $N_e$ depletion region separates EUV plasma from a region of active precipitation in the cusp. The initial high-$N_e$ structuring poleward of the cusp depletion region cannot be created by the direct injection of EUV plasma from lower latitudes.

2. The high-$N_e$ plasma structures poleward of the westward $V_e$ channel appear to be the result of particle impact ionization that is superimposed on either EUV ionized plasma or the baseline $N_e$ of the polar cap.

3. The newly-created and highly-structured plasma evolves into lower-$N_e$ less structured polar cap patches as they transit the polar cap. These are the first in situ observations of a series of patches, entrained in the polar cap flow, traveling from their source in the cusp to the nightside auroral oval.

4. These observations contrast the classical view of patch formation in which patches come from the TOI and structure is added by the GDI. We observe precipitation that produces large $N_e$ structures [e.g., Smith et al., 2000] near noon that convect across the polar cap and smooth into classic polar cap patches.

These data have the potential to improve initialization conditions in patch simulations, allowing for better predictions of patch irregularities and forecasting of space weather Global Navigation Satellite Systems scintillation effects. Multi-point sequential SWARM measurements could also be used for future studies of the processes thought to control polar cap patch dynamics.

Acknowledgments:
The SWARM mission is funded by the European Space Agency. The all-sky imager at Longyearbyen is supported by the Norwegian Research Council. This work was made possible with funds from the International Cooperation in Education, the Canadian Space Agency, and the Natural Sciences and Engineering Research Council of Canada. The Hanksalmi SuperDARN radar is funded by the Radio and Space Plasma Physics Group at the University of Leicester, the authors thank Mark Lester for use of the data. The OMNI data were obtained from the GSFC/SPDF OMNIWeb interface. Magnetic field residuals were calculated by Jan Raurup and Claudia Stolle. This study is a product of the Canada-Norway Rocket Science Training and Educational Program arranged by the University of Alberta, University of Bergen, Queen’s University, Calgary University of Calgary, University of Saskatchewan, University of Tromsø, and the University Centre in Svalbard. The authors would like to thank Rune Flobergen for his guidance.

References: