# Swarm Observation of Field-Aligned Currents in Multiple Arc Systems

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## 1. Introduction

Auroral arcs are usually generated by precipitating electrons and occur in regions of upward field-aligned currents (FACs), however the relation is not one-to-one, since kinetic energy of the current-carrying electrons is also important in the production of auroral luminosity. Multiple auroral arc systems provide an opportunity to study the relation between FACs, electric field and auroral brightness in detail. We have identified two types of FAC configurations in multiple parallel arc systems using ground-based optical data from the THEMIS all-sky imagers (ASIs), and magnetic and electric field instruments onboard the Swarm satellites.

**Unipolar FAC event**: Each arc is an intensification within a broad, unipolar current sheet and downward currents only exist outside the upward current sheet.

**Multipolar FAC event**: Multiple arc systems represent a collection of multiple up/down current pairs.

In this study, we examine the relation between arc multiplicity and the FAC and electric field structure of the multiple arc systems with unipolar and multipolar FACs. The electrodynamic structures of multiple arc system presented in this paper can be used to study where the auroral multiplicity comes from.

## 2. Instrument and Data

**THEMIS ASI:**

THEMIS ASI consists of 21 cameras covering mid- to high-latitude Northern America; it captured 256×256 pixel "white light" images every 3 seconds.

**Swarm Constellation:**

Consists of 3 identical satellites launched on 22nd November 2013 by the European Space Agency (ESA). One pair of satellites (Swarm A and C) fly side by side at 460km. The third satellite (Swarm B) at 510km. Each satellite is equipped with a magnetometer capable of measurements with up to 50 Hz time resolution with precision greater than 0.1nT. Electric Field Instruments (EFI) comprise two thermal ion imagers (TII) and two Langmuir probes (LPs). Cross-track Ion bulk velocity is estimated from the first moment of the ion distribution imaged by the TIIs [*Burchill et al.*, 2010].

## 3. Swarm and DMSP conjunction with multiple arc system

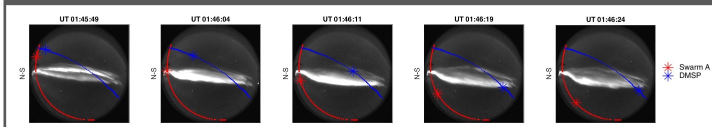


Figure 1. Multiple arc system observed by THEMIS INUV on Jan. 7, 2016 with Swarm A (red) and DMSP (blue) crossings.

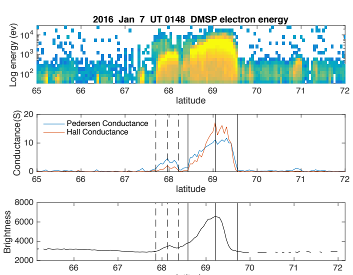


Figure 2. (a) Electron energy flux observed by the DMSP F17 satellite. (b) Pedersen (blue) and Hall (orange) conductances calculated with average energy and energy flux of the electrons [*Robinson et al., 1987*]. (c) Auroral brightness along the DMSP trajectory.

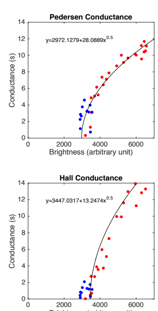


Figure 3. Relation of Pedersen (a) and Hall (b) conductance with DMSP along-track brightness. Red dots represent the brighter arc indicated by the solid vertical lines in Fig. 2. Blue dots represent the arc with dashed vertical lines. Curve fits are applied by assuming a simple relation between conductance and the optical intensity $C = \sqrt{I}$ [*Kosch et al., 1998*].

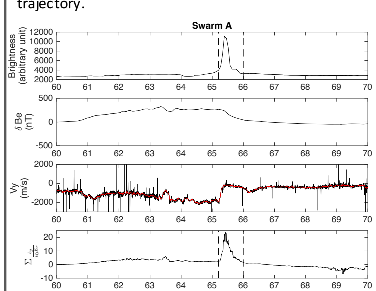


Figure 4. (a) Auroral brightness along Swarm A's trajectory. (b) Residual eastward magnetic field with IGRF model subtracted. (c) Ion drift velocity (approximately eastward) measured by Swarm EFI. 16 Hz data (black) is smoothed to 1 Hz (red). (d) Pedersen conductance estimated with Swarm magnetic and electric field data with the following equation.

$$\frac{E_x}{b_y} = \pm\frac{1}{\mu_0 \Sigma_P}$$

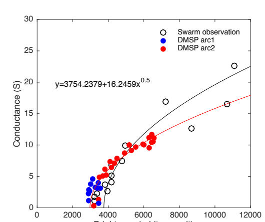


Figure 5. Relation of Pedersen conductance with auroral brightness along the trajectory of Swarm A (black circles and line) and DMSP satellite (red and blue dots represent two arcs).

## 4. Multiple arc system with unipolar and multipolar FACs

### Event 1: 20150315

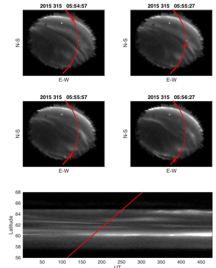

Figure 6(a) Swarm B trajectory and multiple arcs appearing in camera images and satellite aligned keogram.

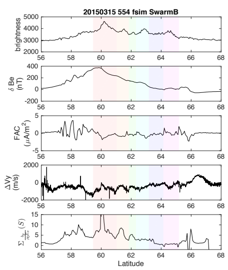


Figure 6(b) Swarm observations of brightness along satellite trajectory, residual magnetic field, FAC, cross-track ion drift velocity and Pedersen conductance.

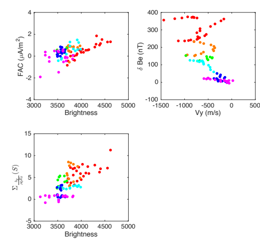

Figure 6(c) Relation between FAC and brightness, magnetic field and ion drift velocity, and Pedersen conductance and brightness.

- **Unipolar FAC; fluctuating electric field; prominent correlation between Pedersen conductance and auroral brightness.**

### Event 2: 20140930

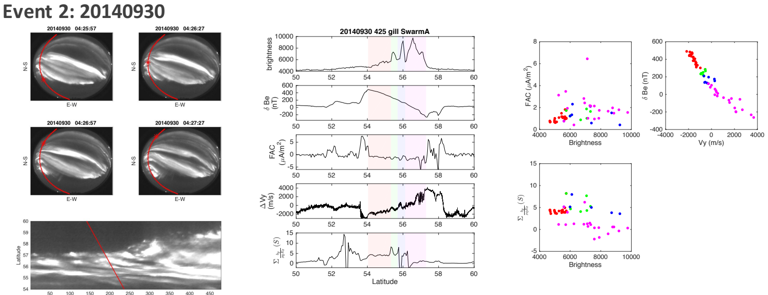


Figure 7. Multiple arc system on September 30, 2014. All the panels are the same as in Figure 6.

- **Unipolar FAC; electric field enhancements on the edges of upward current sheet; uniform conductance over multiple arcs.**

### Event 3: 20140405

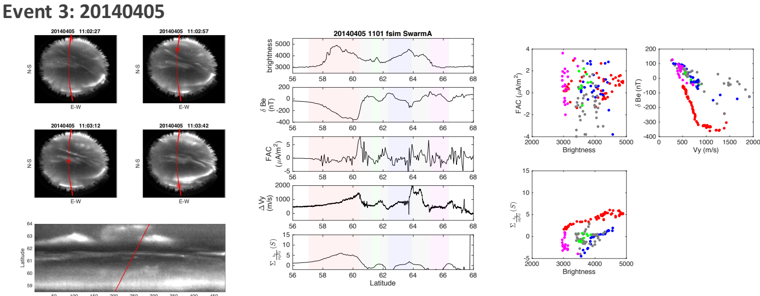


Figure 8. Multiple arc system on April 5, 2014. All the panels are the same as in Figure 6.

- **Multipolar FAC; prominent correlation between magnetic and electric field; uniform conductance within each current sheet; conductance varies from different current sheets.**

## 5. Conclusion

We identified two types of multiple arc events according to FAC configuration, demonstrating their electric fields pattern and Pedersen conductance.

**Unipolar FAC event**: multiple arcs appear on one broad upward current sheet and downward currents only exist outside the upward current sheet. Significant electric field enhancements are shown on the edges of the broad upward current sheet. Electric field fluctuations inside the multiple arc system can be large or small.

**Multipolar FAC event**: multiple arc systems represent a collection of multiple up/down current pairs. A prominent correlation between magnetic and electric field indicate uniform conductance within each upward current sheet.

Understanding the electrodynamics in multiple arc system is important in identifying the arc generator. Further work is needed to study the origins of distinct behaviors of field-aligned currents and electric fields in multiple arc systems., i.e., whether the difference is due to instrumental or physical effects. Do they have different generator structures in the magnetosphere? Do the auroral multiplicities come from the M-I coupling process or the multiple structures of magnetospheric generator?

## 6. References

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[3] Kosch, M. J., T. Hagfors, and K. Schlegel (1998). Extrapolating EISCAT Pedersen conductances to other parts of the sky using ground-based TV auroral images. *Annales Geophysicae*. Vol. 16. No. 5. Springer Berlin/Heidelberg.

## MITC-09

This study is supported by Natural Sciences and Engineering Research Council of Canada, European Space Agency and Canadian Space Agency. Swarm data can be accessed online at http://earth.esa.int/swarm. THEMIS ASI data can be viewed via the University of Calgary data portal located at http://data-portal. phys.ucalgary.ca/.