# Exploring a radial ionospheric current associated with the sunlight terminator


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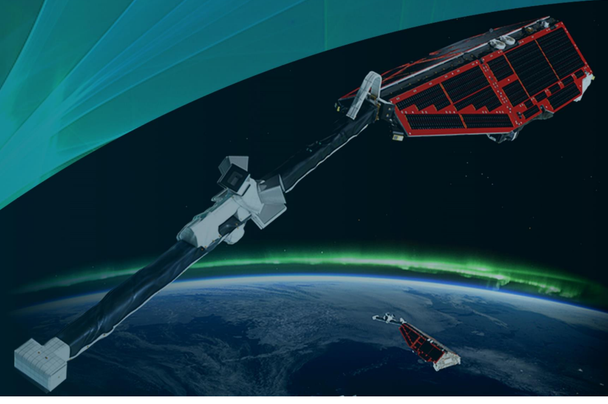


## INTRODUCTION

According to the ionospheric Ohm's law there should be field-aligned currents (FACs) at the sunlight terminator due to conductance gradients. The goal of this research is to find if there is a significant **radial ionospheric** current associated with gradients in the Hall conductance. Previous estimates of the terminator current have predicted relatively strong currents based on a conductance gradient that is probably too strong. Here we use a more realistic smoother model of the solar extreme ultraviolet (EUV) produced conductance.

We present a **theoretical analysis** that uses the Swipe model to characterise the electric field, and the Lompe code to calculate the EUV conductance and resulting magnetic field perturbations. Additionally, we present an **observational analysis** where we calculate the FACs based on vector magnetic field measurements from Swarm A with the CHAOS model subtracted. We are looking at latitudes > 80° to find currents that are not influenced by field-aligned current in the auroral zone and investigate data from orbits that are almost perpendicular to the terminator.

### Ionospheric Ohm's law

We determine the full field-aligned current $j_\parallel$ by taking the divergence of the horizontal height-integrated current of the ionospheric Ohm's law. This results in

$$j_\parallel = \Sigma_P \nabla \cdot \mathbf{E} + \mathbf{E} \cdot \nabla \Sigma_P + \nabla \Sigma_H \cdot (\mathbf{E} \times B)$$

We are interested in the last term. In the observational analysis we **measure** $j_\parallel$ with Swarm and we **predict** the Hall gradient term with Lompe. Then we compare the two.

## THEORETICAL ANALYSIS

- We want to predict the magnetic field perturbations associated with the terminator currents.
- The Lompe (Local mapping of polar ionospheric electrodynamics) technique is used to model the conductances and to get the magnetic field perturbation vectors $B_{north}$ and $B_{east}$ . This represents what we can expect to see in the Swarm data.

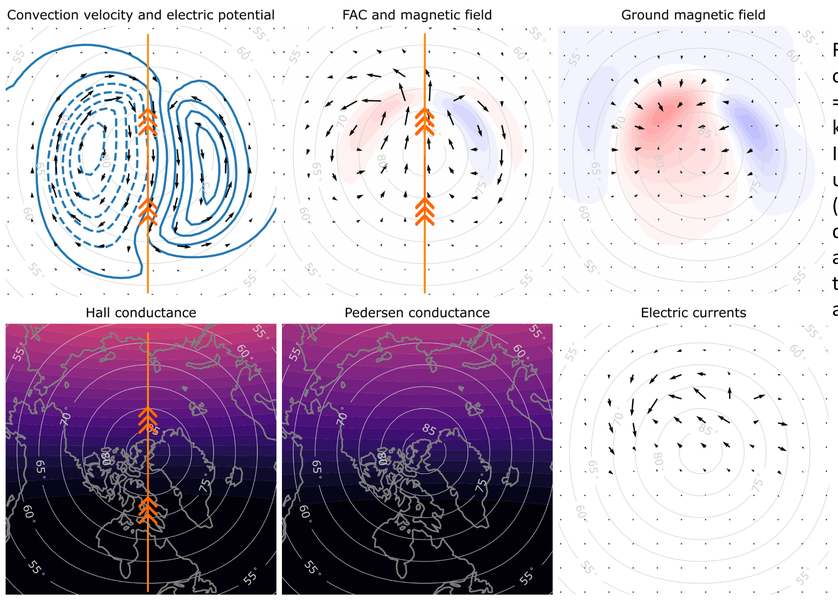



Figure 1: Lompe output for the conditions; Dipole tilt = 0°, F107 = 150, solar wind velocity = 350 km/s, IMF By (GSM) = 0 nT and IMF Bz (GSM) = -3 nT. The upward field-aligned currents (FACs) are shown as red, and downward FACs blue. The orange arrows represent the synthetic track used in the theoretical analysis.

### The Swipe model (Hatch et al., 2023)

- Swipe (Swarm ionospheric polar electrodynamics), is a model for ionospheric convection and ionospheric conductances that combines the electric field model *Swarm Hi-C* and the magnetic field model *AMPS*.
- We use the Swarm Hi-C model to specify the electric field in the Lompe analysis, and to predict the electric field along the satellite track in the observational analysis (Fig 6).

### Lompe (Laundal et al., 2022)

- In the Lompe technique the electric field is modelled in terms of electric charge densities on lines that extend radially.
- The Lompe code determines the Hall and Pedersen conductances **without infinite gradients** at the sunlight terminator by assuming that the neutral atmosphere is radially stratified. In other words, that the Earth is a sphere.
- To mimic the observational analysis we calculate FACs from the Lompe predictions of the crosstrack magnetic field ($B_{ct}$).

### Radial current ($j_z$) derived from $B_{ct}$ (Lühr et al., 1996)

We calculate $j_z$ using the technique described by Lühr et al., and the crosstrack component of the magnetic field measured along the Swarm satellite track.

### Lompe predictions (poleward of 80°)

- Lompe predicts very weak radial currents (grey, in figure to the right) along the synthetic satellite track.
- The Hall gradient term (purple), derived from the electric field and the along-track derivative of the Hall conductance $\partial\Sigma_H$ / $\partial$s (blue line), is stronger, but balanced by the $\nabla \cdot \boldsymbol{E}$ term.
- Notice that the scale is nA/m², and not μA/m²

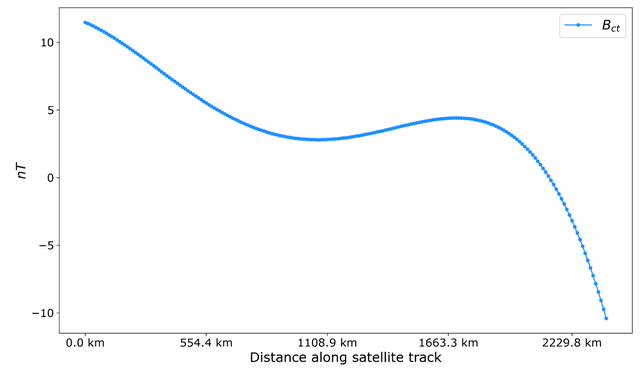
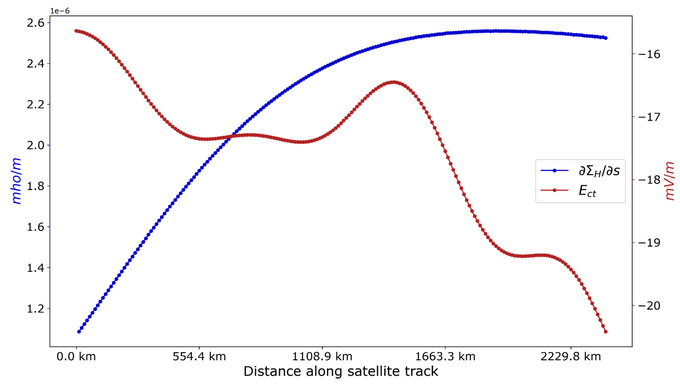
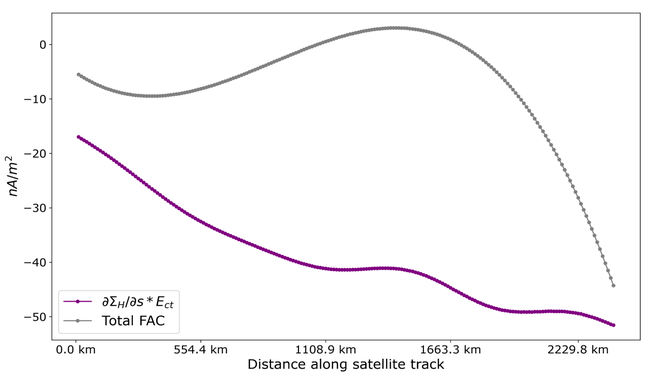



Figure 2: Polynomial fit of B-crosstrack along the synthetic orange track plotted in figure 1. The x-axis shows the distance from the start of the track at 80° latitude, going over the North Pole and back to 80°.




## OBSERVATIONAL ANALYSIS

- We present a case study based on Swarm A data from the 1st of March 2016, from midnight to 9AM. Here, the terminator (dotted red in figure 6) is slightly equatorward of 80°. Swarm crosses the terminator from noon to midnight in the north and from midnight to noon in the south.
- We focus on the region poleward of 80° latitude to avoid auroral conductance, which is less predictable than conductance due to EUV radiation. The tracks are plotted in Quasi-Dipole coordinates and projected onto a polar grid. Noon (12AM) points towards the Sun.
- We chose tracks that cross the terminator at an almost perpendicular angle to maximise the observed conductance gradient.
- We use the Swipe model to get the electric field and plot the estimated current ($\partial\Sigma_H$ / $\partial$s * $\boldsymbol{E}$), in orange, against the measured current $j_r$, in blue. We are smoothing the $B_{ct}$ which is incorporated in the $j_r$ curve over 120s because we are looking at large scale currents.
- Swarm electric field measurements mainly meausure the along-track component, and were not used for these orbits.

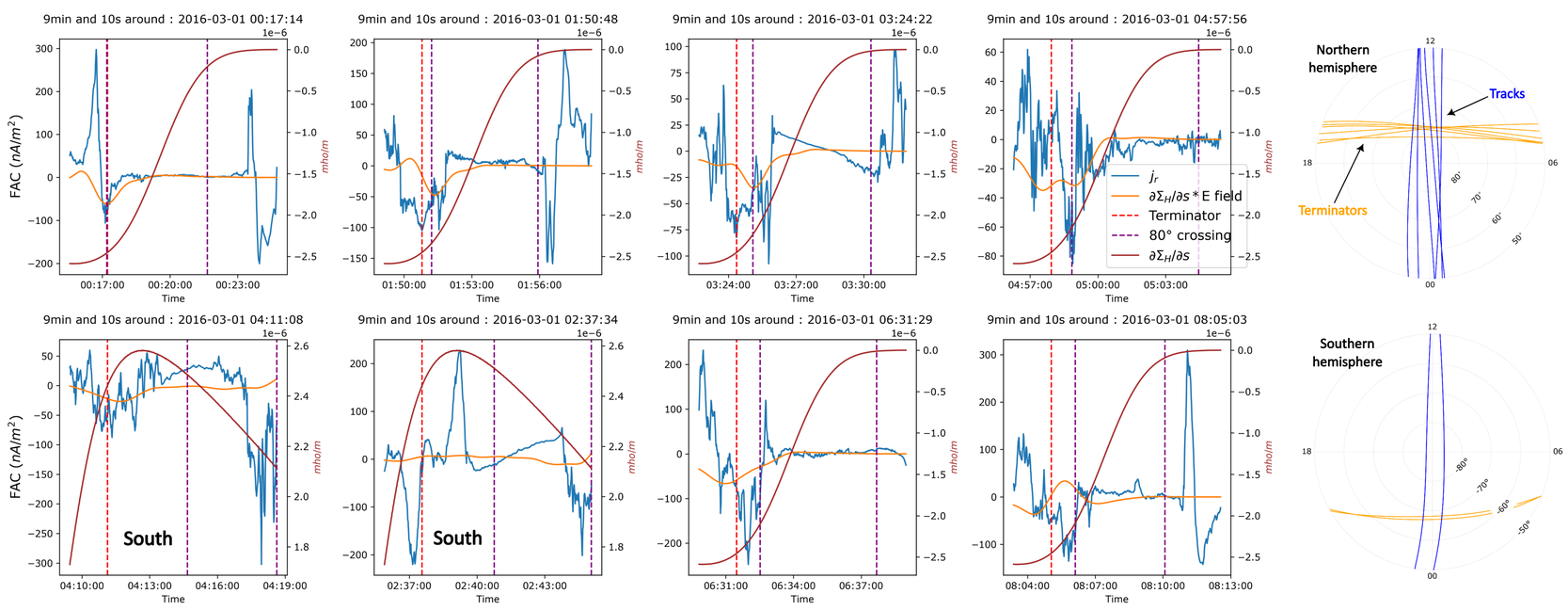



Figure 6: This panel shows 8 Swarm A tracks crossing their associated sunlight terminators. 6 plots show the northern hemisphere and 2 plots show the southern. The blue curve is the measured radial current and is smoothed over 120s to filter out high frequencies. The orange curve is the predicted current.

## CONCLUSIONS

- Our goal is to find if there is a radial ionospheric current associated (blue) with gradients in the Hall conductance (orange).
- Figure 6 shows ambiguous results. Some correlation appears to be present between the measured (blue) and predicted signal (orange), but the results are not consistent in all crossings. The region of increased Hall conductance gradient (brown) is large and smooth.
- The structures in the predicted terminator current are mainly due to variations in the electric field and not due to the conductance gradients which are smooth.
- In future work more events should be analysed and compared. Appropriate events would be noon-midnight and have the terminator more in the polar cap.


References

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