New understanding of multiscale field-aligned currents and scientific and technological impact on the magnetosphere-ionosphere-thermosphere system

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Abstract

Field-aligned currents (FACs), or the system of currents flowing along Earth's magnetic field lines, are the dominant form of energy and momentum exchange between the magnetosphere and ionosphere. FACs are ubiquitous across the high-latitude region and have unique characteristics depending on the magnetospheric or solar wind source mechanism, and, therefore, mapping location in the ionosphere (i.e. auroral zone, polar cap, cusp). Further complicating the picture, FACs also exhibit a large range of spatial and temporal scales. In order to create new understanding of FAC spatial and temporal scales, their cross-scale effects, and the impact on the polar region, including on critical technologies, new data analysis approaches are required. This talk addresses a coherent progression of investigation in three parts: 1) an exploration of the characteristics, controlling parameters, and relationships of multiscale FACs using a rigorous, comprehensive analysis across multiple spacecraft observations; 2) augmentation of these statistical results with detailed case studies, fusing observations from diverse platforms and incorporating critical information about the high-latitude electrodynamics across scales; and 3) a quantitative investigation of the impact on Global Navigation Satellite System (GNSS) signals. We find that the relationships between FAC scales are complex and reveal new information about the connection between multiscale FACs and irregular space weather activity. Additionally, there are observable signatures of multiscale FACs and resultant electrodynamic activity in ionospheric data from GNSS signals, suggesting that these signals are affected distinctly according to scale size of the coupling process. Our results indicate that GNSS data may be a powerful source of information about the multiscale near Earth space environment.

New understanding of multiscale field-aligned currents and scientific and technological impact on the magnetosphere-ionosphere-thermosphere system

McGranaghan et al. [2017]

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This poster in 30 seconds

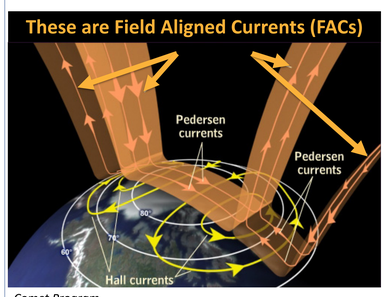
FAC characteristics do not map trivially across small-scales (~10–150 km, <1° latitudinal width), mesoscales (~150–250 km, 1–2° latitudinal width), and large-scales (>250 km)

Relationships between scales exhibit strong local time dependence, with particularly **strong differences at dayside local times**

Differences across scales **coincide with `anomalous' behavior in the near Earth space environment**

Introduction

Multiscale processes, or those which contain important features across multiple scales in time and/or space, characterize the near-Earth space environment. Multiscale effects are particularly important to understand interactions between regions, where numerous processes contribute to the dynamics.

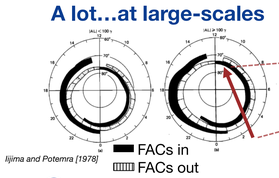


Comet Program

In the solar wind-magnetosphere-ionosphere system, currents flowing along Earth's magnetic field lines, or field-aligned currents (FACs), provide the dominant form of energy and momentum exchange. FACs are, therefore, a critical component of the space weather environment and are **inherently multiscale**.

What do we know about FACs?

A lot…at large-scales

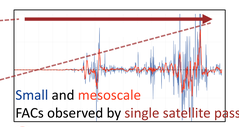


Iijima and Potemra [1978]

FACs in
FACs out

- ✔ Characteristics
- ✔ Dependence on interplanetary magnetic field (IMF)
- ✔ Dependence on solar zenith angle (SZA)

However, the picture changes at smaller scales



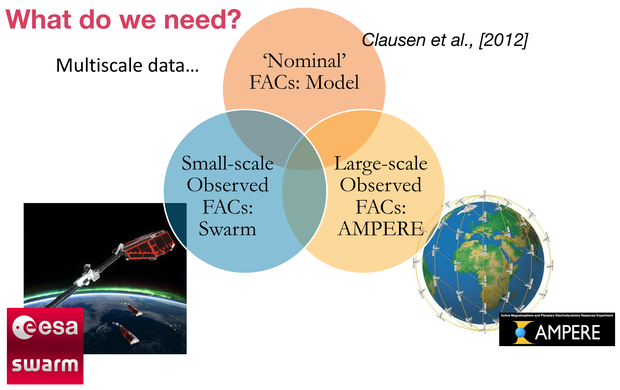
- ✘ Characteristics
- ✘ Dependence on IMF
- ✘ Dependence on SZA
- ✘ Relationship between scales

Can we study multiscale FACs?

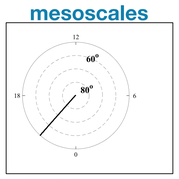
What do we need?

Multiscale data…

Clausen et al., [2012]

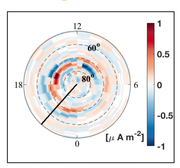


Observed Small- and mesoscales



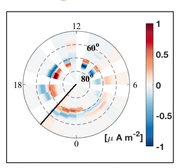
Single Swarm pass
(50° to highest latitude)

Observed Large-scales



Global AMPERE FACs
(during time of Swarm pass)

Modeled Large-scales



Global model (Clausen et al., [2012])
(model fit to AMPERE data)

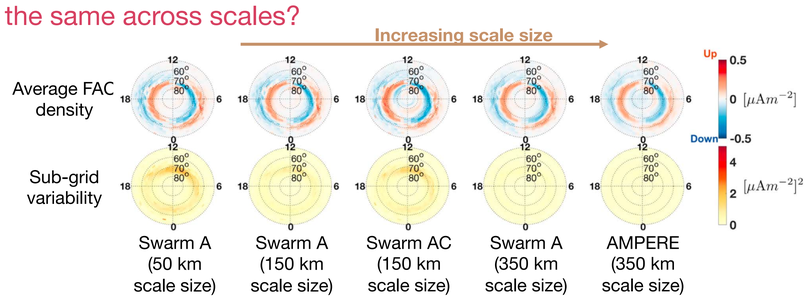
…with statistics compiled over years

New multiscale understanding

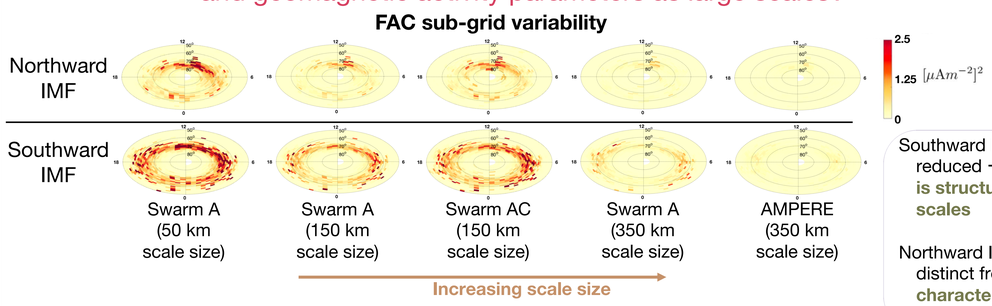
1 Are the characteristics of FACs the same across scales?

Average distributions consistent across scales and reflect well-known large-scale FACs

Variability distributions reveal significant differences across scales pronounced at dayside (~70-80° latitude) and nightside (~60-70°) local times



2 Do small-scale and mesoscale FACs exhibit similar dependencies on solar wind and geomagnetic activity parameters as large scales?



Southward IMF: Small-scale structure is reduced → **magnetosphere-ionosphere is structured across larger spatial scales**

Northward IMF: Small-scale structure more distinct from large-scales → **different characteristics across scales influence FACs' dependence on drivers**

3 To what extent do observed FACs depart from the large-scale picture typically used to model the currents, and does this departure depend on the scale size?

We use Degree of Departure (DoD) to quantify 'anomalous' FAC behavior

Observed (disturbed state) – Nominal (background state) = Degree of departure

Observed = Swarm or AMPERE

Nominal = *Clausen et al.,* [2012] model

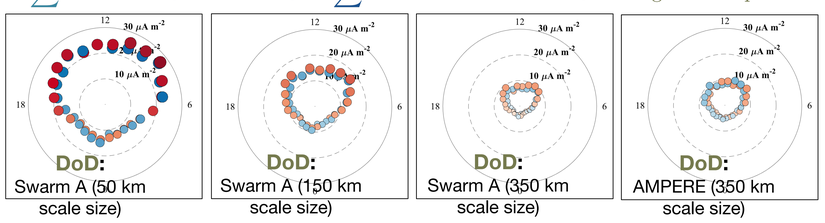
Median of differences across ~22,000 Swarm passes between 2015-2016

- Away from ionosphere (upward FAC)
- Toward ionosphere (downward FAC)

Size and distance from center of polar plot indicate magnitude of ***DoD***

$$\sum \text{Upward Observed FACs} - \sum \text{Upward nominal FACs} = \text{Degree of Departure}$$

$$\sum \text{Downward Observed FACs} - \sum \text{Downward nominal FACs} = \text{Degree of Departure}$$

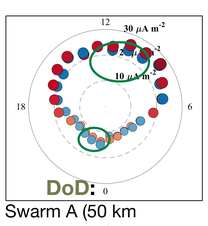


DoD does not map trivially across scales, indicating that large scales may be insufficient to describe FAC dynamics (i.e., large and small scales are significantly different)

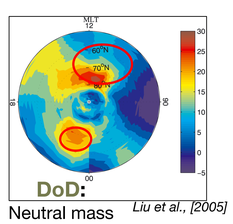
Distributions of DoD **heavily a function of local time**

Are small- and mesoscale FACs the key to the next level of near-Earth space understanding?

1 What is the impact on the near-Earth space environment?



Swarm A (50 km scale size)



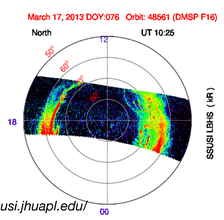
Neutral mass density (%)

Liu et al., [2005]

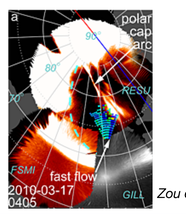
Locations of large **FAC DoD** correspond to large Joule heating and **neutral mass density DoD**

Physical connection between areas of greatest difference between small-scale, mesoscale, and large-scale FACs and locations of anomalous Joule heating and neutral mass density enhancement

What data are untapped to explore the connection? Bonus



https://ssusi.jhuapl.edu/



Zou et al., [2015]

What's next?

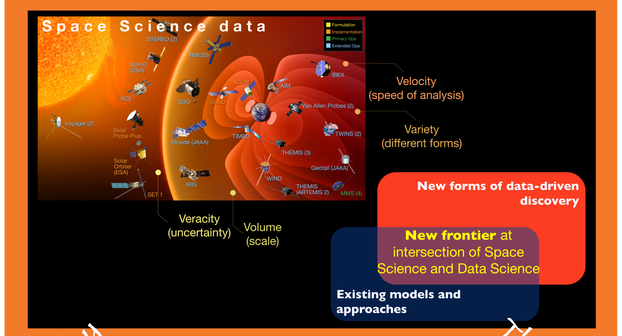
Model the impact in global circulation models (GCMs)

SA41B-3482 – Boundary-oriented convection and particle precipitation patterns and their impacts on Joule heating — Thursday

Utilize advanced data-driven methods and intelligent observational systems

Tuesday — SM23B-04: First-Light Observations from the Transition Region Explorer (TREx) Ground-Based Network

A New Frontier



Tuesday — SA23C-3200 Ushering in a new frontier in geospace through Data Science

Thursday — Town Hall: Data Science and a New Scientific Frontier in Space Science

What should you remember?

FAC characteristics do not map trivially across across small-scales (~10–150 km, <1° latitudinal width), mesoscales (~150–250 km, 1–2° latitudinal width), and large-scales (>250 km)

Differences across scales could be responsible for 'anomalous' (i.e., unexplained) behavior in near-Earth space environment

Novel data science-driven discovery is critical to progress in space science:

'New frontier' of space weather research can be built on intersection of existing approaches and new data science-driven discovery

Learn more, collaborate, and build on this work

https://github.com/rmcgranaghan/AGU-2018