Kp and IMF effect on hemispheric asymmetry in ionospheric horizontal and field-aligned currents during different seasons

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Background

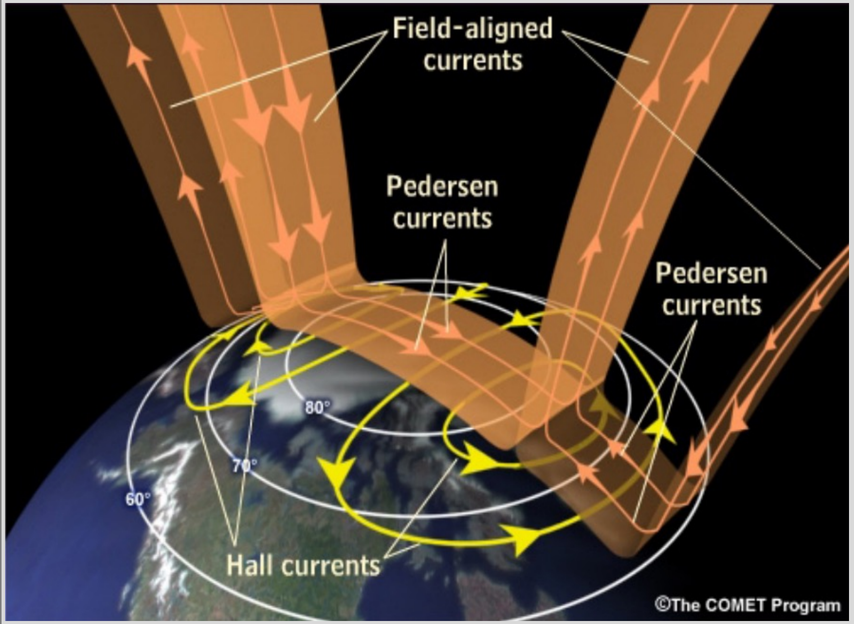
Current systems in the polar regions

- Field-aligned currents (FACs)
  – Approximately **radial** at high latitudes

- E-region horizontal currents
  – **Curl-free** (CF) part
  – **Divergence-free** (DF) part

- Often **approximately** may assume
  – Curl-free ≈ Pedersen
  – Divergence-free ≈ Hall

- Estimate the currents from satellite magnetic field data



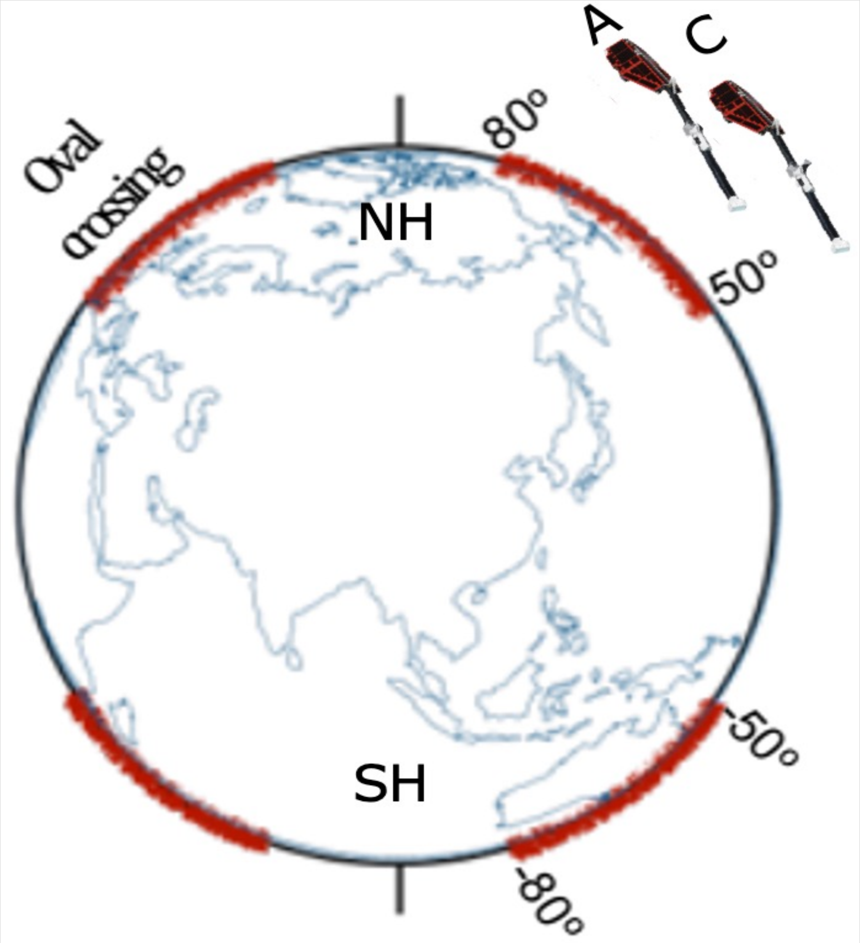
Motivation

Are the currents in the Northern Hemisphere (NH) and Southern Hemisphere (SH) equal on a statistical basis?

- **Previous studies show some differences in currents in the NH and SH**
  - Coxon et al.(2016), Laundal et al. (2016), Huang et al. (2017), Smith et al. (2017) and Workayehu et al. (2019)
- In Workayehu et al. (2019), we found about **10% more intense currents in the NH than in the SH, but only during low Kp** conditions.
- We extend the analysis carried out in Workayehu et al. (2019) by studying the effect of seasons (Workayehu et al., JGR2020) and IMF (Workayehu et.al., to be submitted to JGR) on hemispheric asymmetry in currents

Magnetic field data analysis

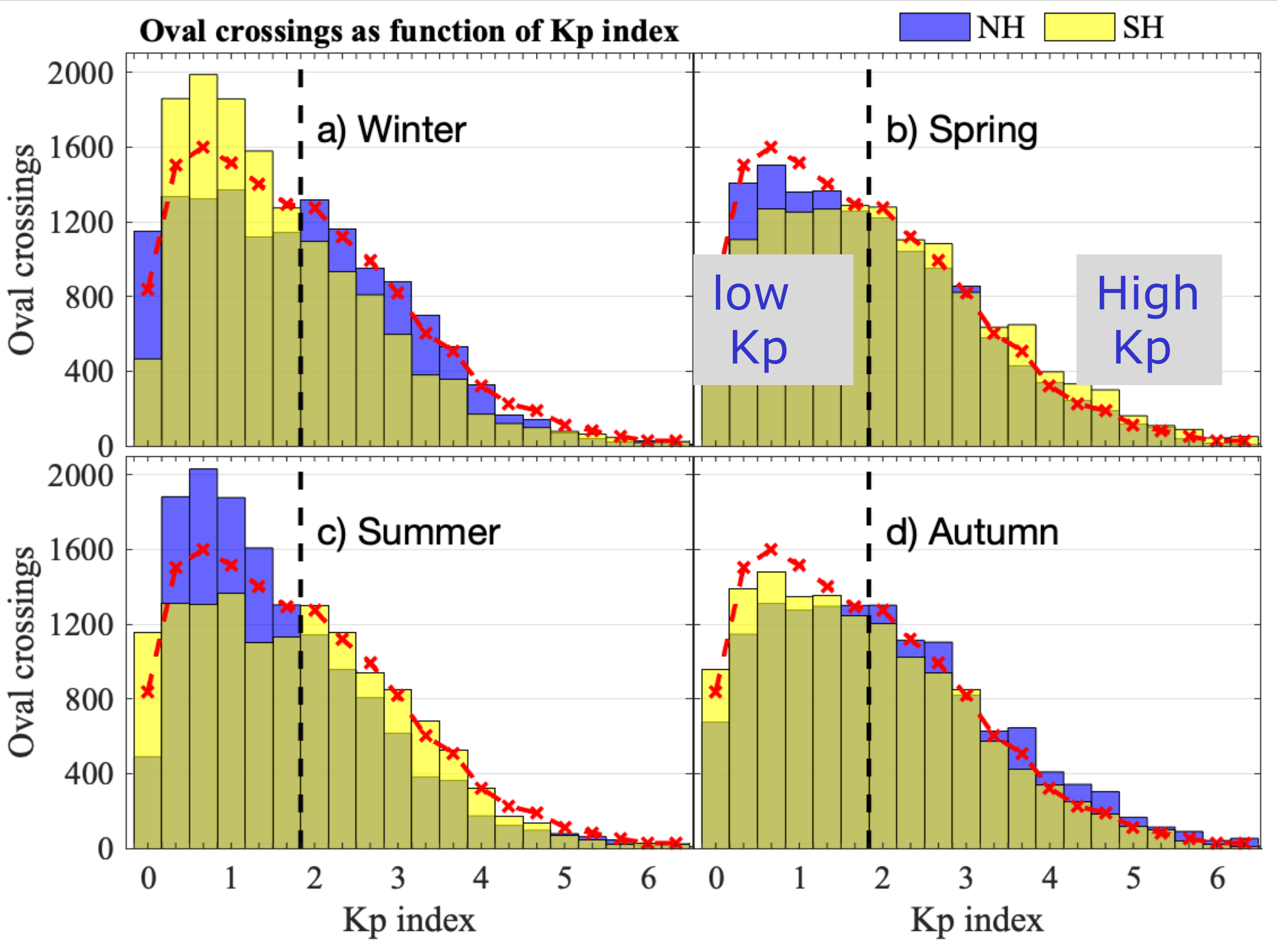
- 1 Hz magnetic data from Swarm A and C
  - Remove background **B** using CHAOS model
  - Four oval crossings between [±50°, ±80°] magnetic latitudes.



- FACs and ionospheric horizontal currents are calculated from the residual magnetic field using the **Swarm Spherical Elementary Current System** (**Swarm/SECS**) method [Amm et al., 2015, Vanhamäki et al., 2020]
- Horizontal current **J** and radial current (FAC) are related by

$$j_{||} = \pm \nabla \cdot \mathbf{J}.$$

Statistical analysis with bootstrapping



Distribution of oval crossings as a function of Kp (Workayehu et al. JGR2020)

Sorting data based on Kp

- Data→ 4 local seasons → low (Kp <2) and high (Kp ≥ 2) activity conditions
- Use bootstrap re-sampling to
  - ➢ Remove the seasonal bias → equal number of samples from each season in each Kp bin

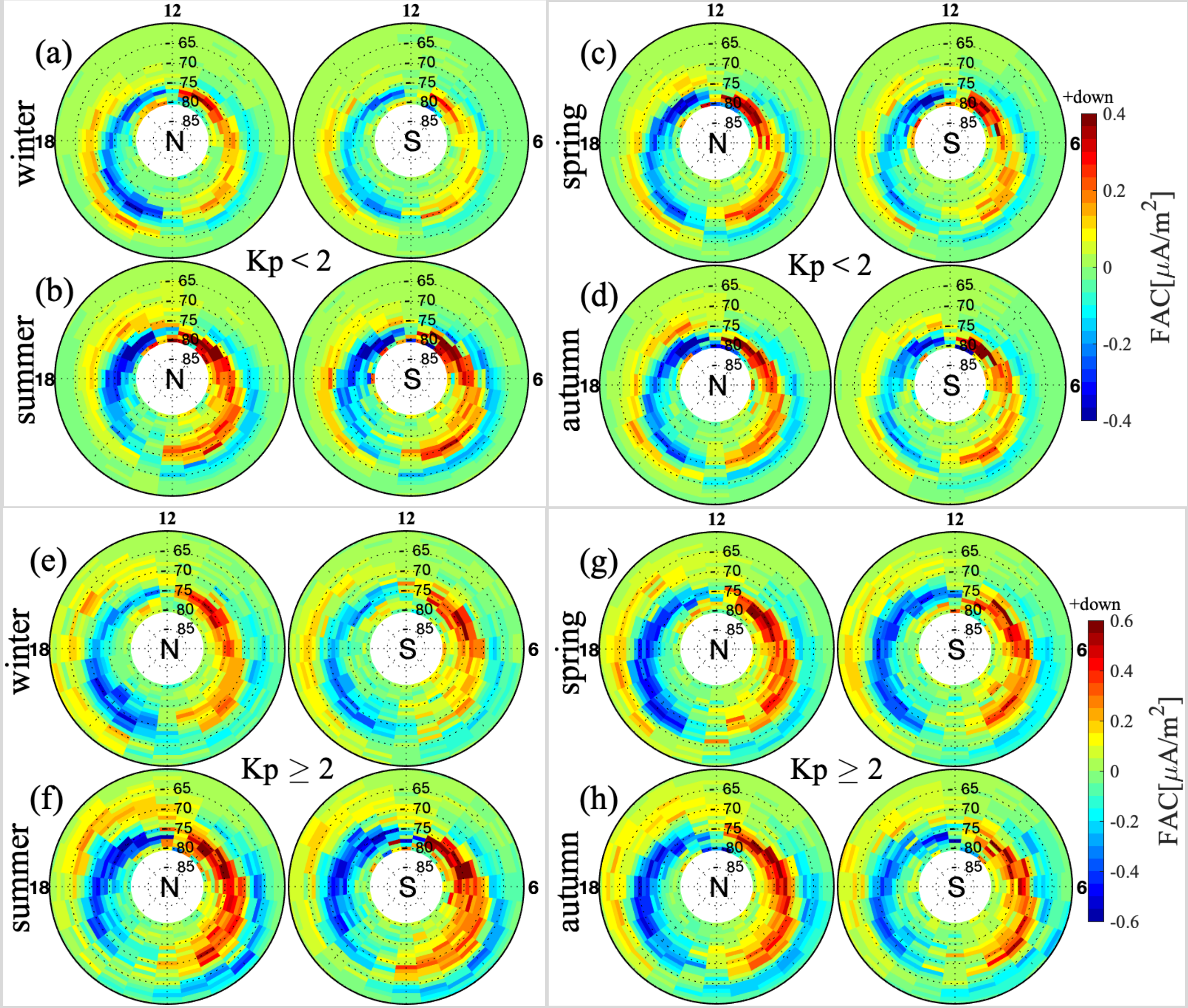
Sorting data based on IMF

- Data→ 4 local seasons → 4 IMF sectors
  - ➢ OMNI data → Newell's coupling function (NCF)
    - ➢ Bootstrap → remove the seasonal bias in each IMF sector using NCF

Asymmetry in FACs: Kp dependence

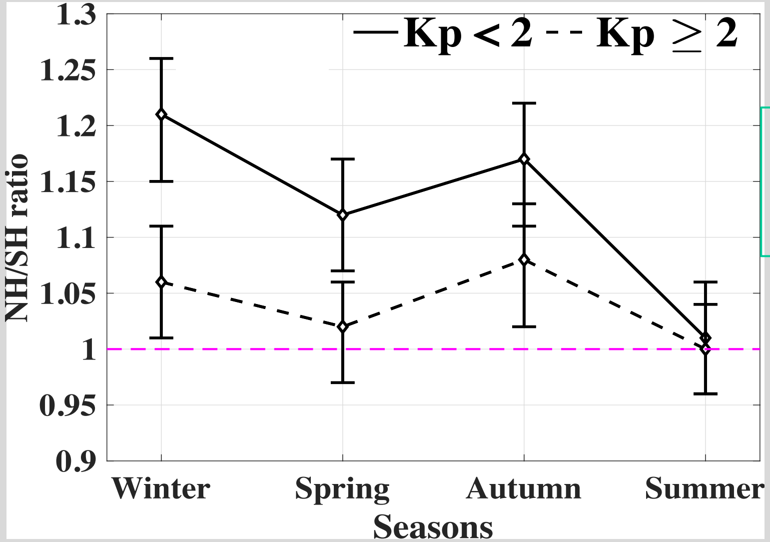
Low Kp

High Kp



Distribution of median FAC density for low Kp (<2) and high Kp (≥ 2) (Workayehu et al., JGR2020)

NH/SH ratio of integrated FACs



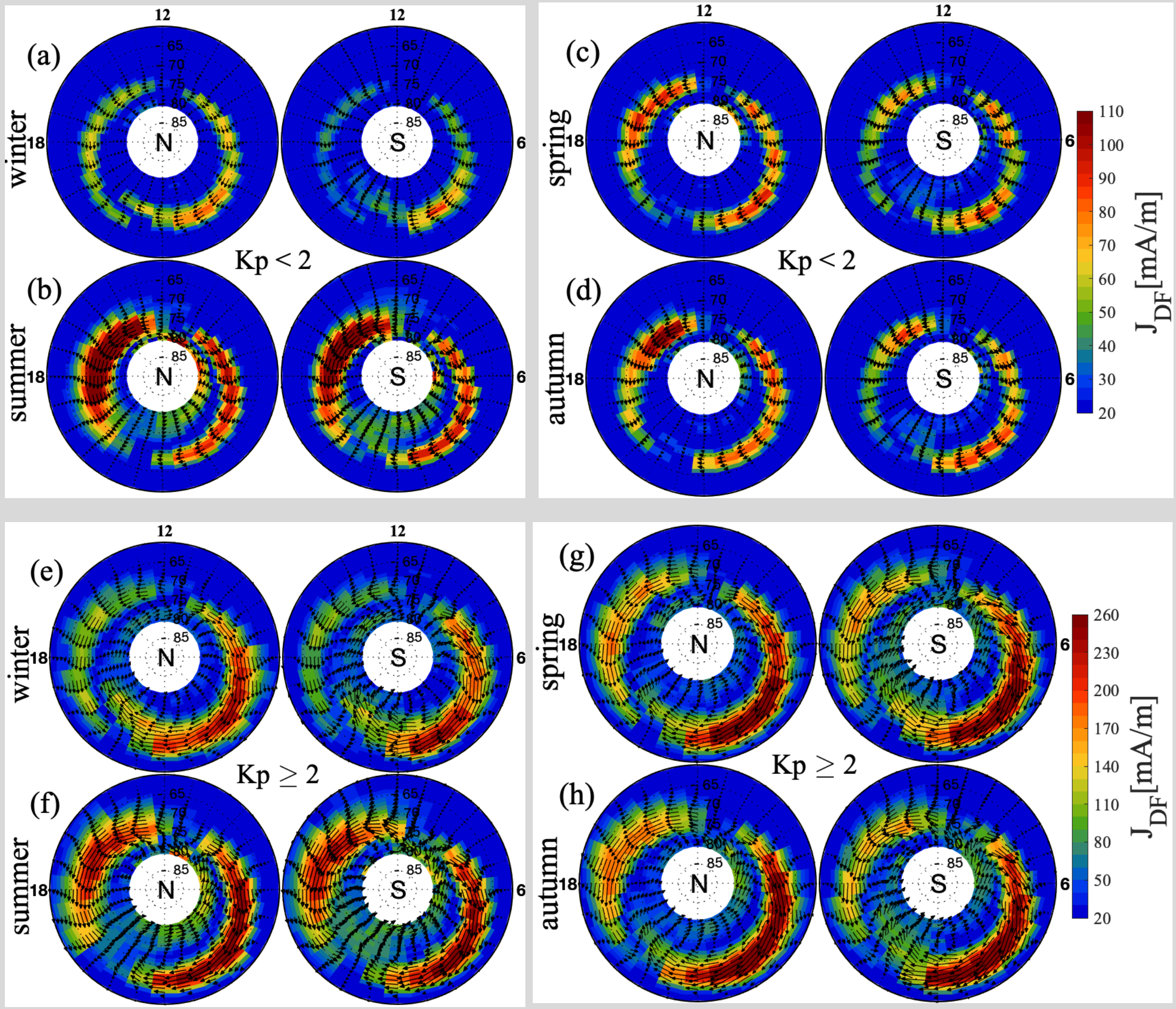
Int. b/n [60º, 80º]

NH/SH ratio				
Kp	winter	spring	autumn	Summer
<2	1.21±0.06	1.12±0.05	1.17 ±0.06	1.01 ± 0.05
≥2	1.06±0.05	1.02±0.05	1.08 ±0.06	1.00 ± 0.04

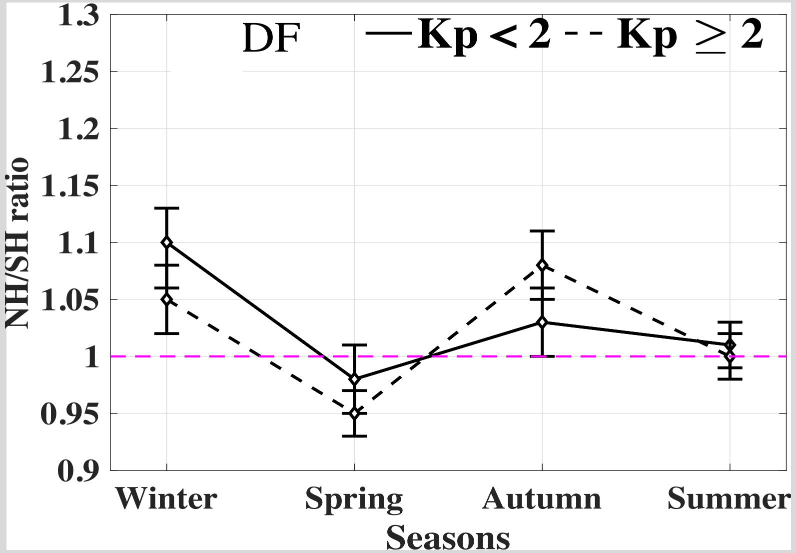
- Largest asymmetry during **winter** and **autumn** for **Kp <2** conditions
- Similar asymmetry in CF currents (not shown)

Asymmetry in DF current: Kp dependence

Low Kp | High Kp



Distribution of DF current for low Kp (<2) and high Kp (≥ 2) conditions (Workayehu et al., JGR2020)

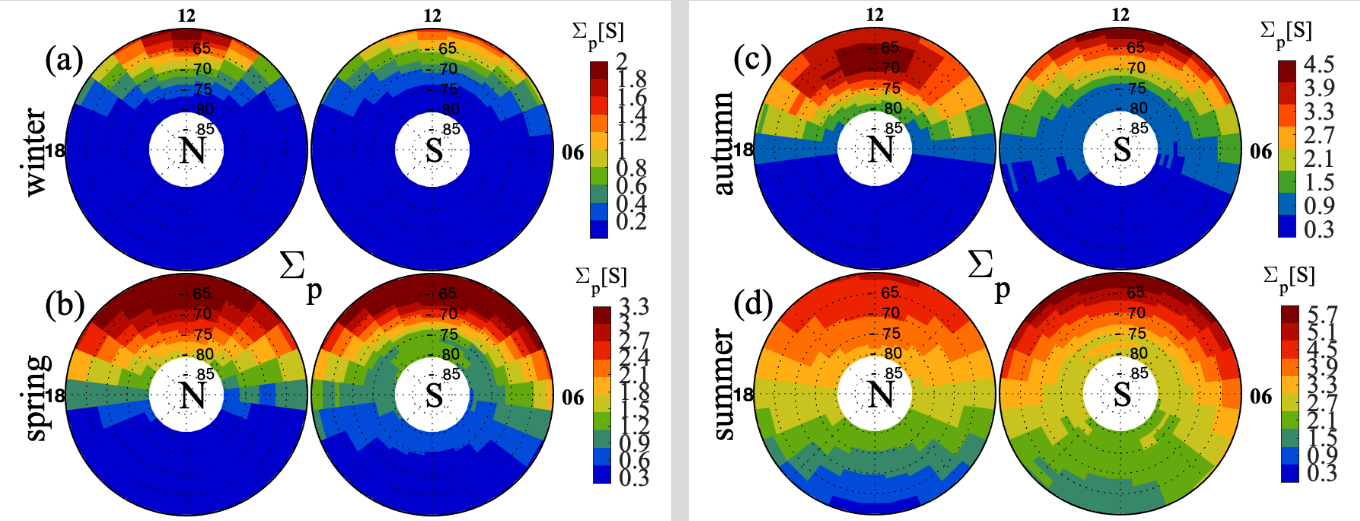


NH/SH ratio				
Kp	winter	spring	autumn	Summer
<2	1.10 ± 0.04	0.98± 0.03	1.03 ± 0.03	1.01 ± 0.02
≥2	1.05 ± 0.03	0.95± 0.02	1.08 ± 0.03	1.00 ± 0.02

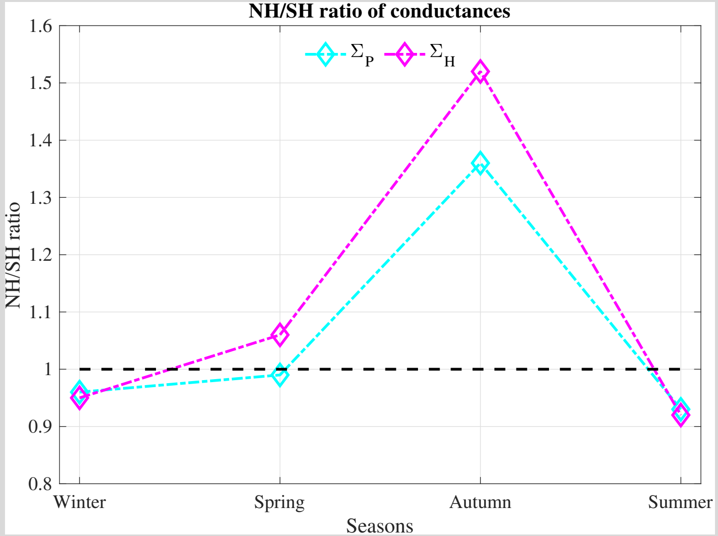
- Largest asymmetry **during winter for low Kp** and **during autumn for high Kp**

Conductances from IRI model

- Can the ionospheric background conductivity explain the observed current asymmetry?



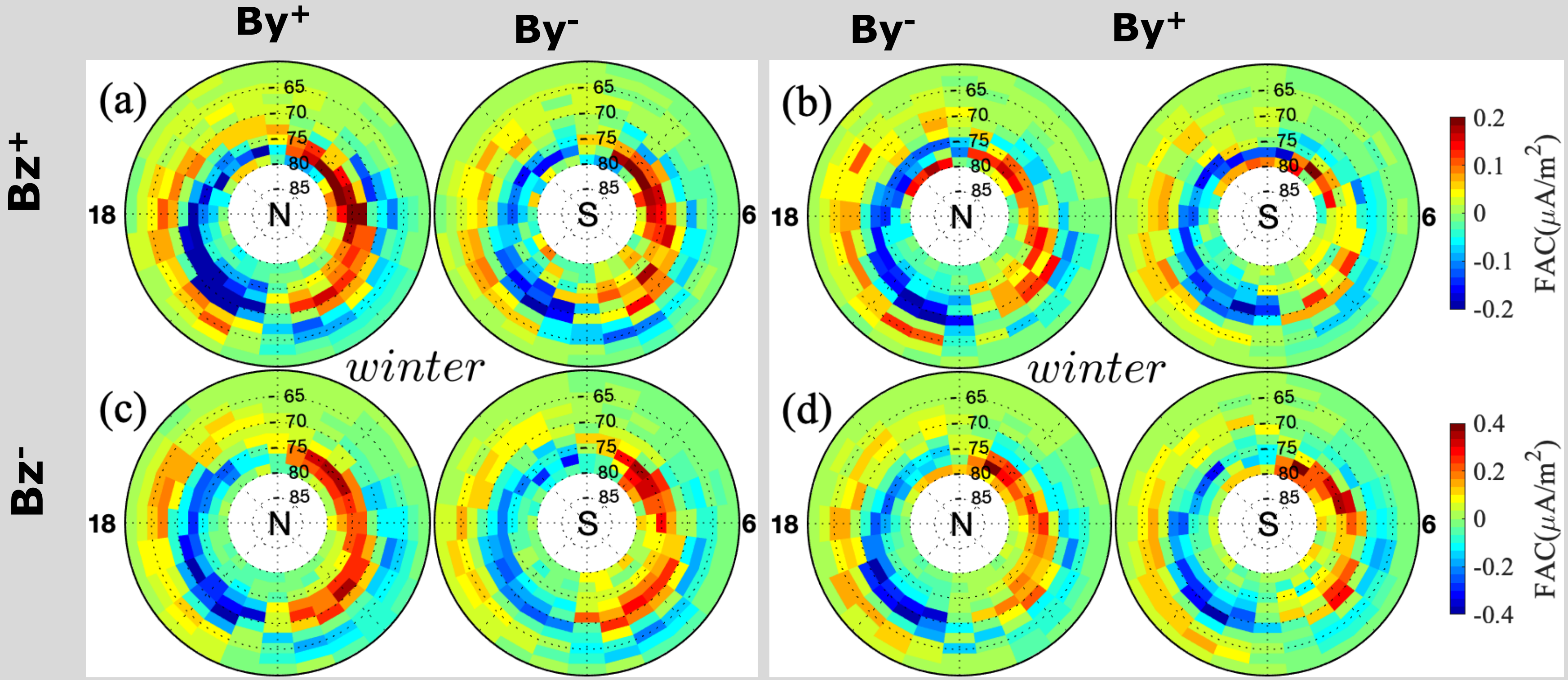
Distribution of Pedersen conductance averaged over 00-24 UT (Workayehu et al., JGR2020)



NH/SH ratios of average Pedersen and Hall conductances within the auroral oval

- Model calculations indicate some hemispheric differences in the average conductances, but they do not seem to fully explain the observed hemispheric asymmetries in the currents.
- Furthermore, conductances based on the IRI-model have the following features/problems
    - ➢ Small nighttime average conductances, especially during winter
    - ➢ No auroral oval is produced

IMF effect on auroral currents in NH & SH

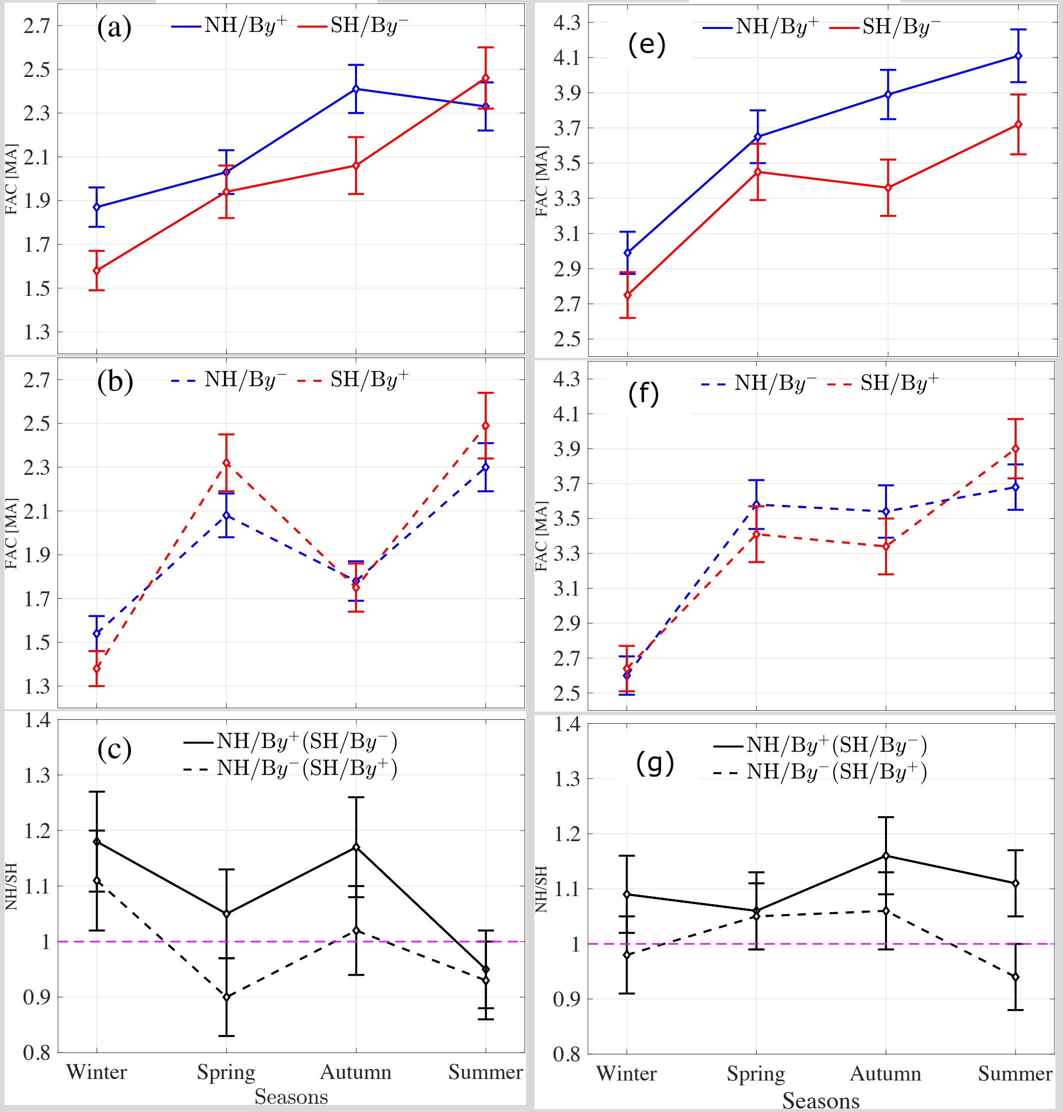


Distribution of FACs (Workayehu et.al.2021, submitted to JGR)

- IMF **By⁺** in NH and **By⁻** in SH causes larger FACs than vice versa.
- By effect is stronger during **IMF Bz⁺** than **Bz⁻**.
- Similar **By** effect is seen on CF and DF currents (not shown).

IMF effect on hemispheric asymmetry

FAC: Bz⁺ **FAC: Bz⁻**

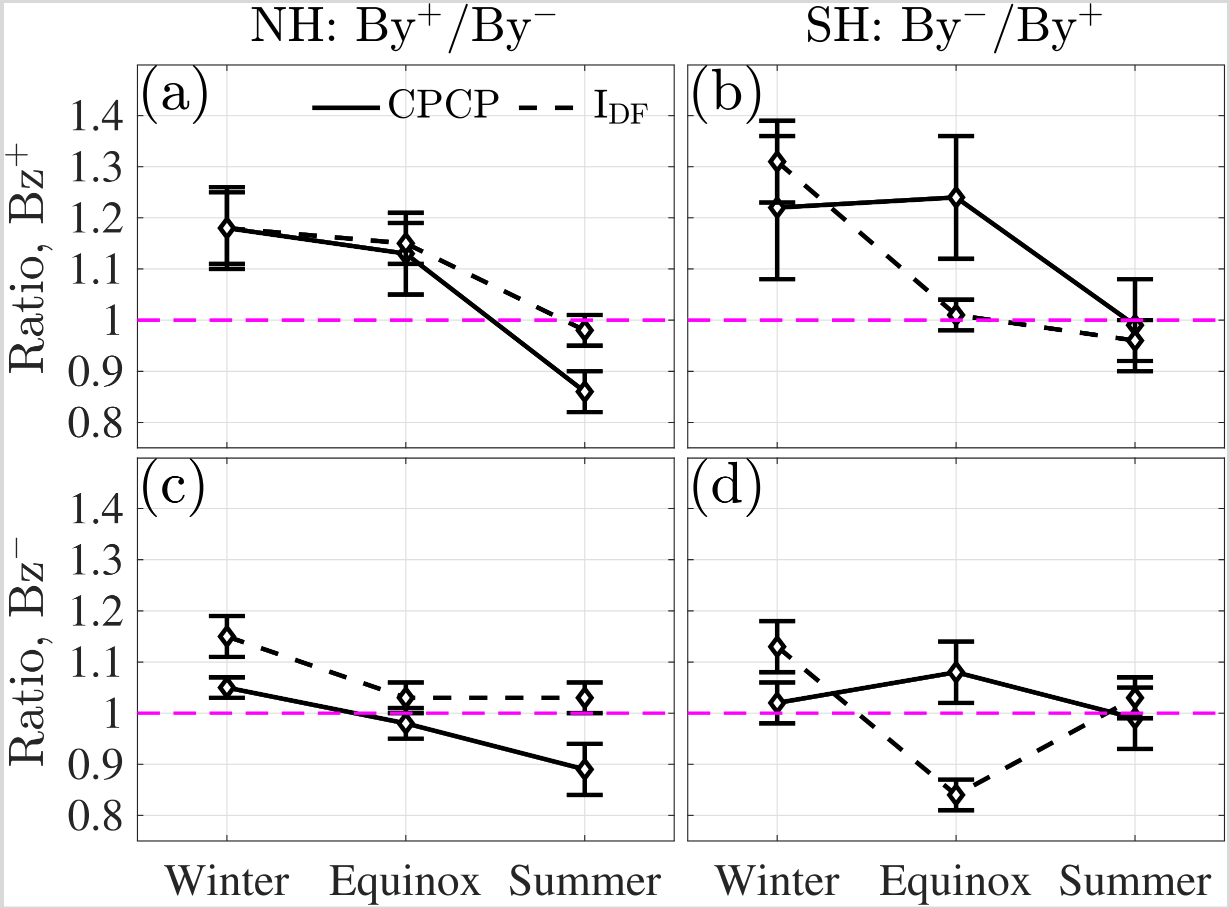


Integrated FACs and NH/SH ratios for Bz^+ (left panels) and Bz^- (right panels) (Workayehu et.al.2021, submitted to JGR)

- To study the By effect, we switch sign between the NH and SH
- **For Bz^+ (IMF northward)**
  - On average, currents are stronger in NH than in SH for By^+ in NH (By^- in SH), see panel (a)
  - NH/SH maxima in winter and autumn for By^+ in NH (By^- in SH), see panel (c)
- **For Bz^- (IMF southward)**
  - On average, currents are stronger in NH than in SH for By^+ in NH (By^- in SH), see panel (e)
  - NH/SH maxima in autumn for By^+ in NH (By^- in SH), see panel (g)
- Similar asymmetry is seen on CF and DF currents (not shown)

Cross polar cap potential (CPCP) from SDDM model

- Can convection electric field explain the observed By effect on currents and hem. asymmetry?



Ratios of CPCP (solid line) and DF current (dashed line) in NH (a, c) and in SH (b, d) during IMF Bz^+ (a, b) and Bz^- (c, d) (Workayehu et.al.2021, submitted to JGR)

- **IMF By** has similar effect on currents and CPCP for **IMF Bz^+** in winter for both hemispheres, at equinox for NH and in summer for SH.

- Generally, within each hemisphere the CPCP shows the same seasonal **IMF By** dependence as the currents for **IMF Bz^+** but can not explain the hemispheric asymmetry (not shown).

Summary and conclusions

- Hemispheric asymmetry is larger during **low (Kp<2)** than **high (Kp≥2),** and during **local winter** and **autumn** than local summer and spring.

- **IMF By$^+$** in NH and **By$^-$** in SH causes larger auroral currents than vice versa. Effect is stronger for **IMF Bz$^+$** than **Bz$^-$.**

- Hemispheric asymmetry in auroral currents is larger for **By$^+$** in NH (**By$^-$** in SH) than vice versa during both signs of IMF **Bz**

- During **IMF Bz$^+$**, the **By** effect on currents can tentatively be explained by the **CPCP** in most of the seasons.

- **Solar induced conductivities** from IRI and **CPCP** from SDDM model do not fully explain the observed hemispheric asymmetry in auroral currents.

- The physical mechanisms producing the hemispheric asymmetry are not presently understood, but the role of auroral conductance due to particle precipitation need to be studied.

Thank you for your interest!

Do not hesitate to contact
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