Seasonal effect on hemispheric asymmetry in ionospheric horizontal and field-aligned currents

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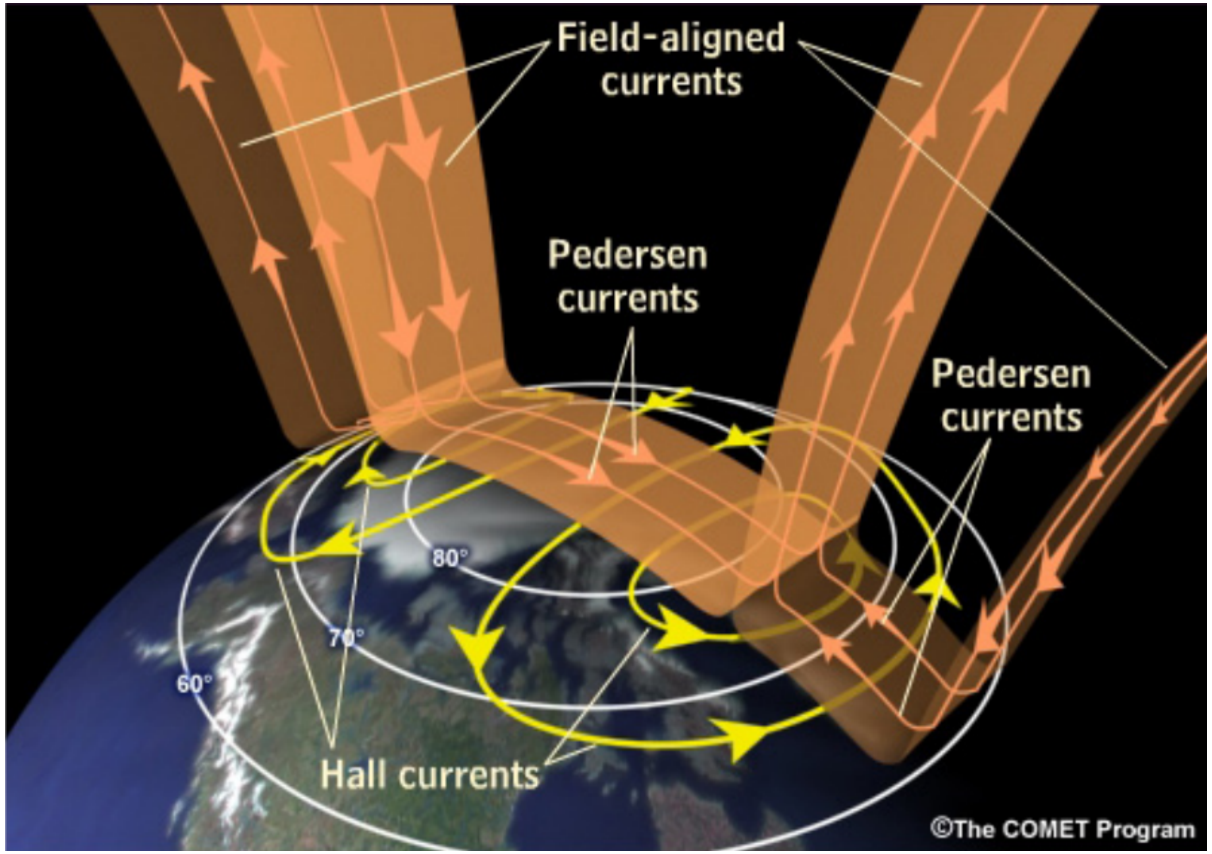
Current systems in the polar region

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

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

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

- Try to estimate the currents from satellite magnetic data



Motivation

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

Possible **hemispheric differences were reported** in previous studies based on satellite measurements of currents. In previous studies, it has been reported that both the **FAC and horizontal currents are possibly more intense in the NH** than in the SH [e.g., Coxon et al.(2016); Huang et al. (2017);

Motivation (cont.)

In Workayehu et al.(2019) https://doi.org/10.1029/2019JA026835, we examined hemispheric asymmetry in auroral currents averaged over all local seasons during low (Kp < 2) and high (Kp ≥ 2) geomagnetic activity conditions

- 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 on the hemispheric asymmetry in the auroral currents during low and high geomagnetic activity conditions.

Swarm magnetic data (cont…….)

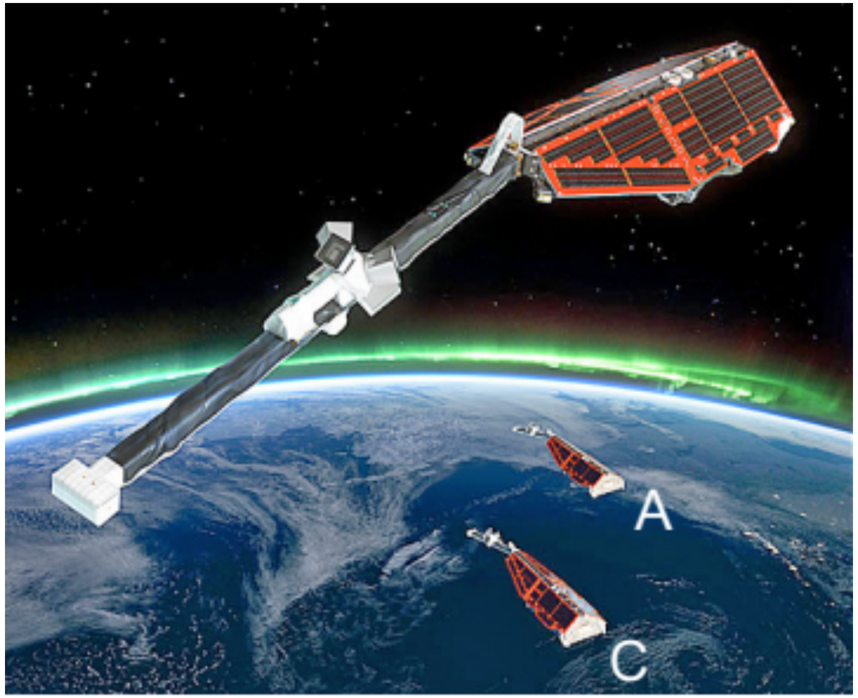
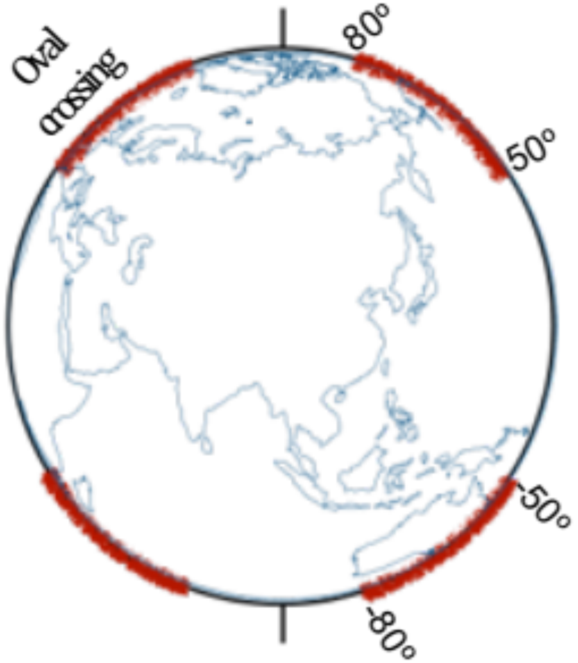


Fig. Swarm constellation from ESA



- 1 Hz magnetic data from Swarm A and C
- Remove CHAOS-6 model

  → ionospheric currents from the residual

- Each orbit is divided into four oval crossings between [50°, 80°] and [-50°, -80°] magnetic latitude.

Magnetic field analysis

- The **Swarm Spherical Elementary Current System** (**Swarm/SECS**) [Amm et al., 2015, Vanhamäki et al., 2020] analysis method is used to analyze the vector magnetic field data.

- Place Curl-Free (CF) and Divergence-Free (DF) SECS around satellite paths (in E-region) $\rightarrow$ fit to data $\rightarrow$ calculate horizontal current **J**

- Radial current (FAC) from the divergence of the horizontal current **J**

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

– Example: one oval crossing 07-05-2017, UT 16:43-16:51

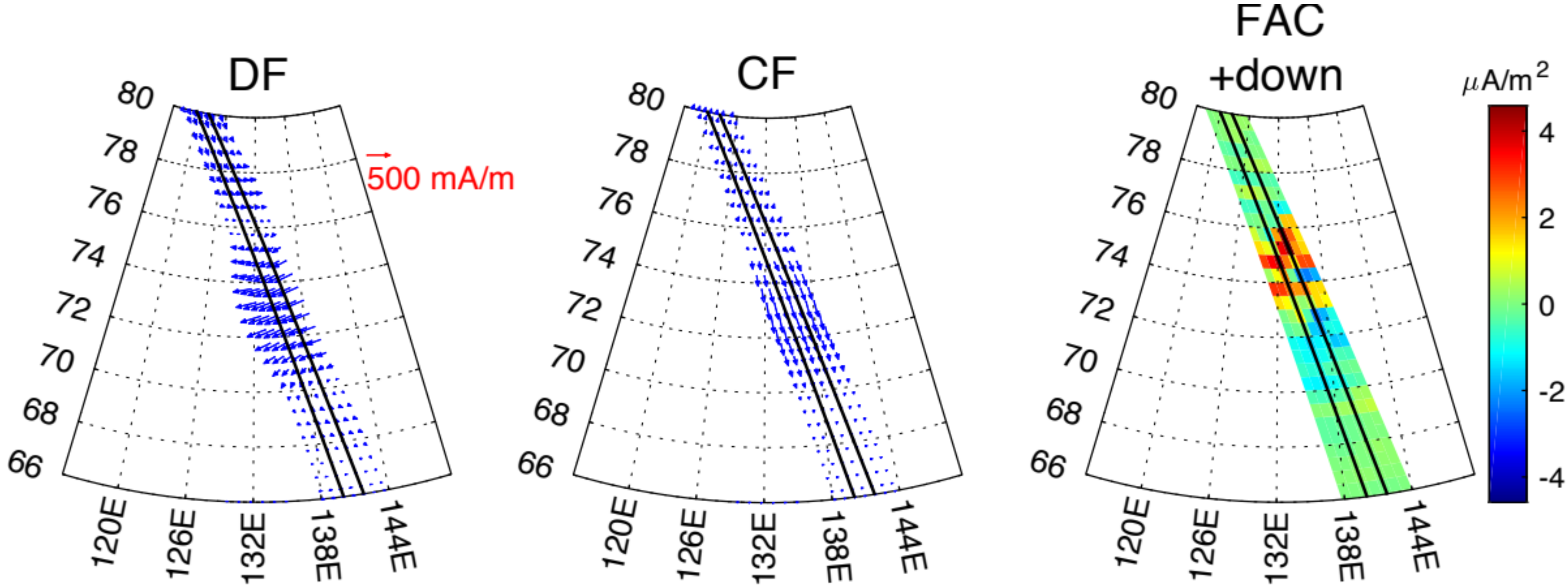


Fig: 2D maps of DF-current, CF-current and FAC (Workayehu et.al., 2019)

Statistical analysis with bootstrapping

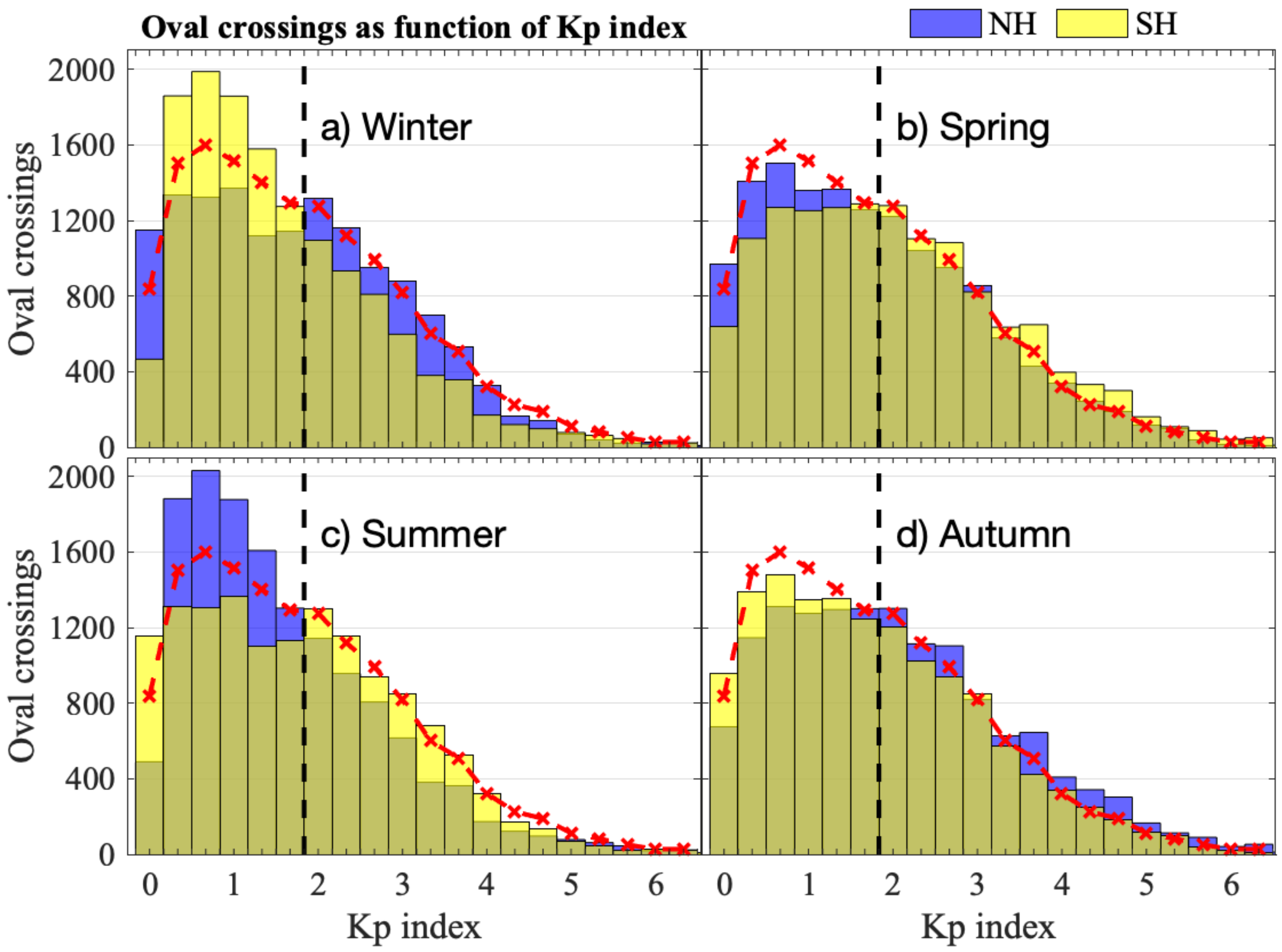


Fig: Distribution of oval crossings as a function of Kp

- Five years of Swarm data April 2014 - April 2019
  - 4 local seasons → low (Kp <2) and high (Kp ≥ 2) activity conditions
- There are seasonal variations in the number of oval crossings & Kp distribution
- Use bootstrap re-sampling to
  - Remove the seasonal bias → **equal number of samples from each season in each Kp bin**
  - Estimate 90% confidence intervals

Statistical analysis with bootstrapping (cont.......)

- **Bootstrapping**
  - 1000 bootstrap samples for each local season
  - Results between the satellite tracks
  - Bin data to 1^{o} AACGM latitude by 1 h MLT grid
  - Calculate mean values in each grid cell for each of the 1000 bootstrap samples

- Integrate average current densities between [60^{o}, 80^{o}] AACGM latitudes
  - **North to South hemispheric (NH/SH) ratios** for each bootstrap sample
    - Median NH/SH ratios
    - 90% confidence intervals

Seasonal dependence of asymmetry in FACs

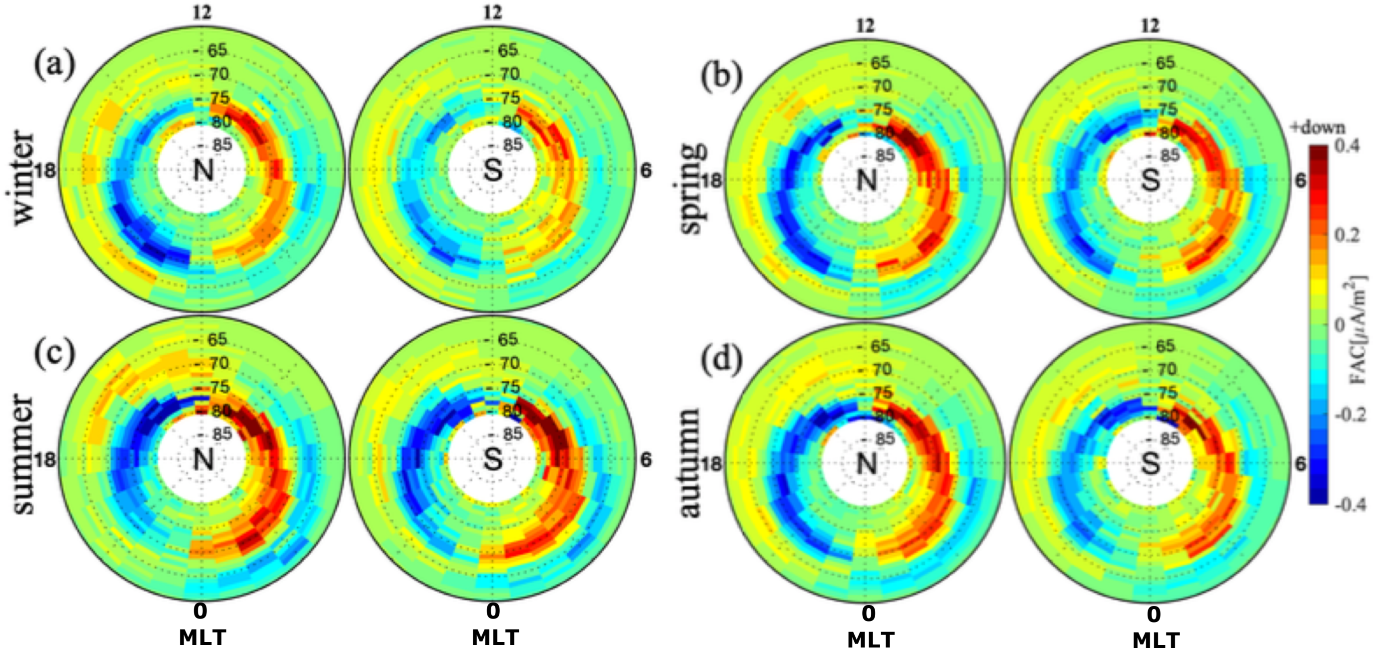


Fig: Distribution of median FAC density

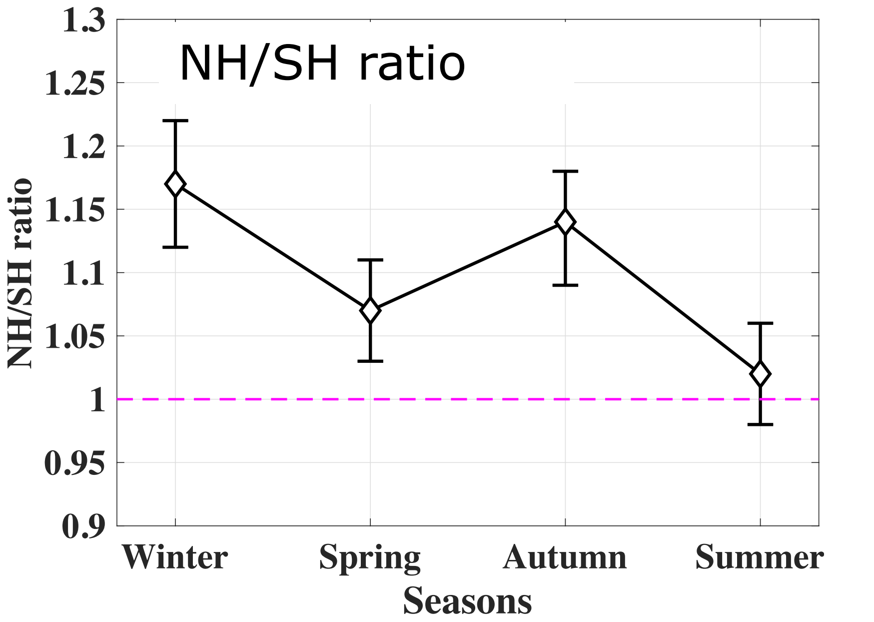


Fig: Seasonal variation of median NH/SH

NH/SH ratio

Kp	winter	spring	autumn	summer
$<6^+$	1.17 ± 0.05	1.07± 0.04	1.14 ± 0.05	1.02 ± 0.04

- Largest hemispheric asymmetry in winter and autumn
- Larger seasonal variation in the SH than in the NH

Seasonal dependence of asymmetry in CF-currents

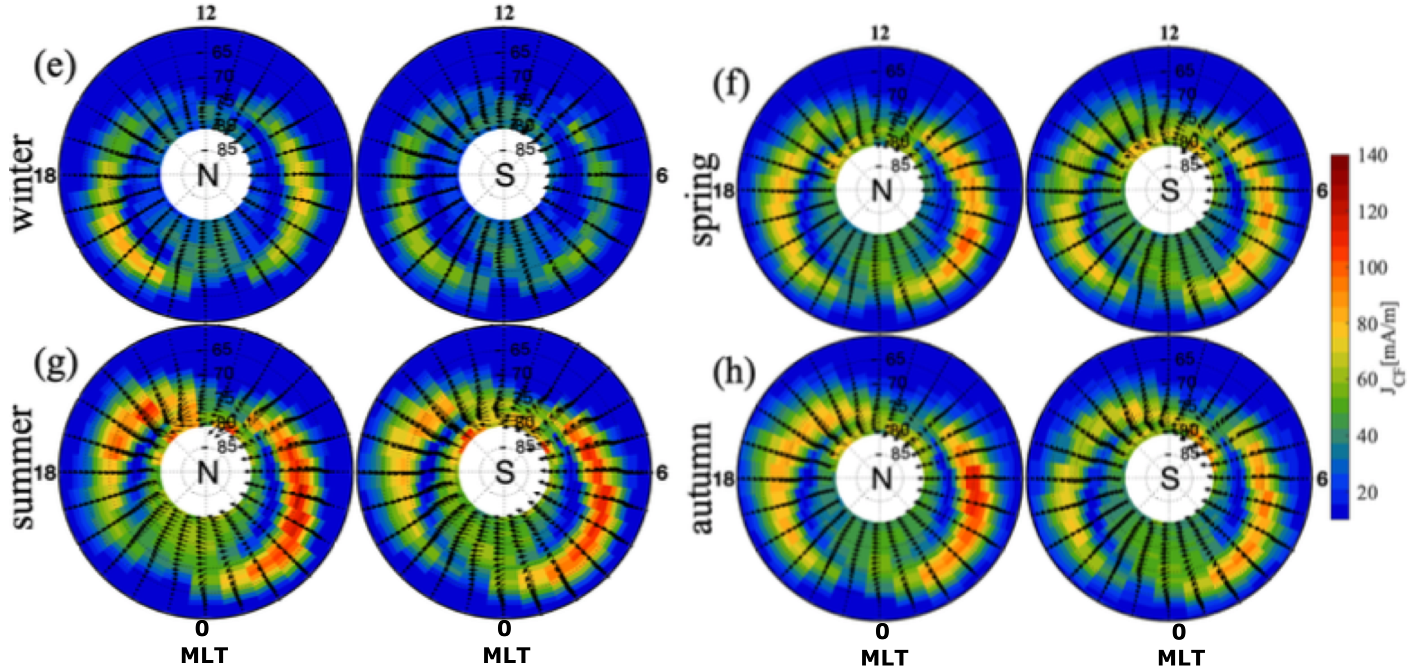


Fig: Distribution of median CF-current density

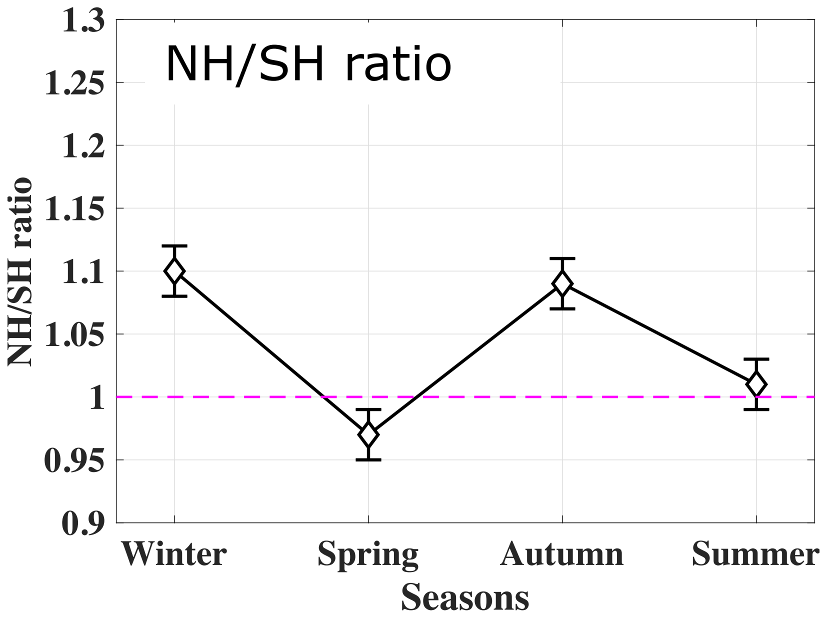


Fig: Seasonal variation of median NH/SH

NH/SH ratio

Kp	winter	spring	autumn	summer
<6$^+$	1.10 ± 0.02	0.97± 0.02	1.09 ± 0.02	1.01 ± 0.02

- Largest hemispheric asymmetry in winter and autumn
- Larger seasonal variation in the SH than in the NH

Seasonal dependence of asymmetry in DF-current

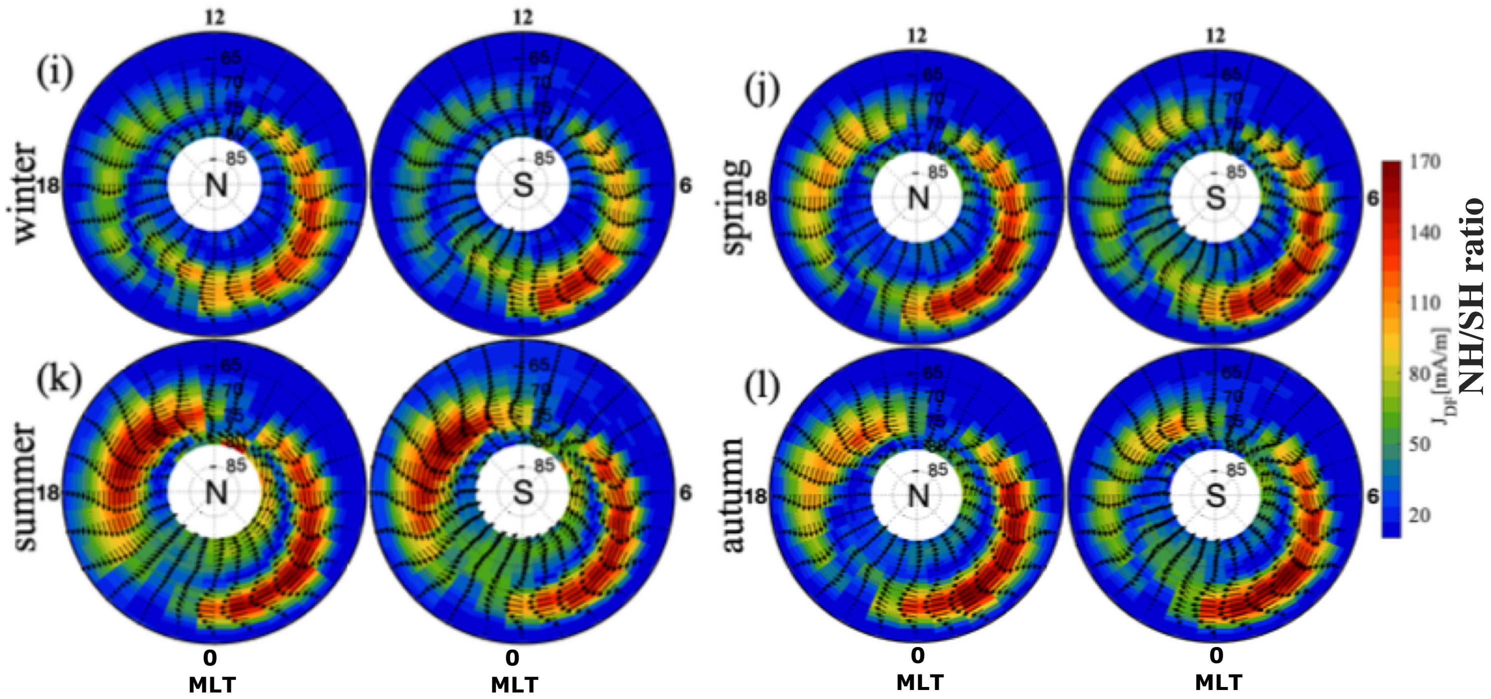


Fig: Distribution of median CF current density for Kp <2 and Kp ≥ 2.

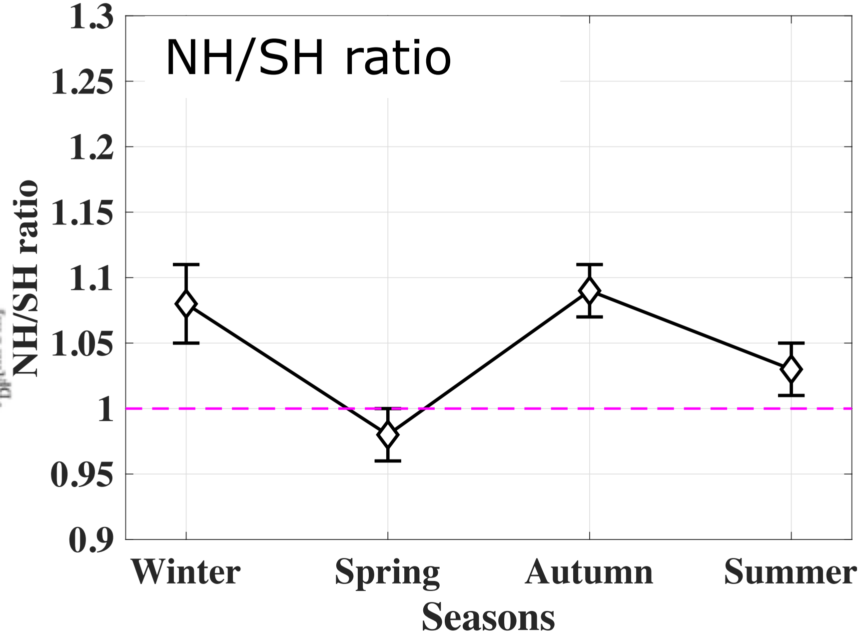


Fig: Seasonal variation of median NH/SH

NH/SH ratio

Kp	winter	spring	autumn	summer
$<6^+$	1.08 ± 0.03	0.98±0.02	1.09 ± 0.03	1.03 ± 0.02

- Largest hemispheric asymmetry in winter and autumn
- Seasonal dependence is stronger in the EEJ than in the WEJ

Kp and seasonal dependence of asymmetry in FAC

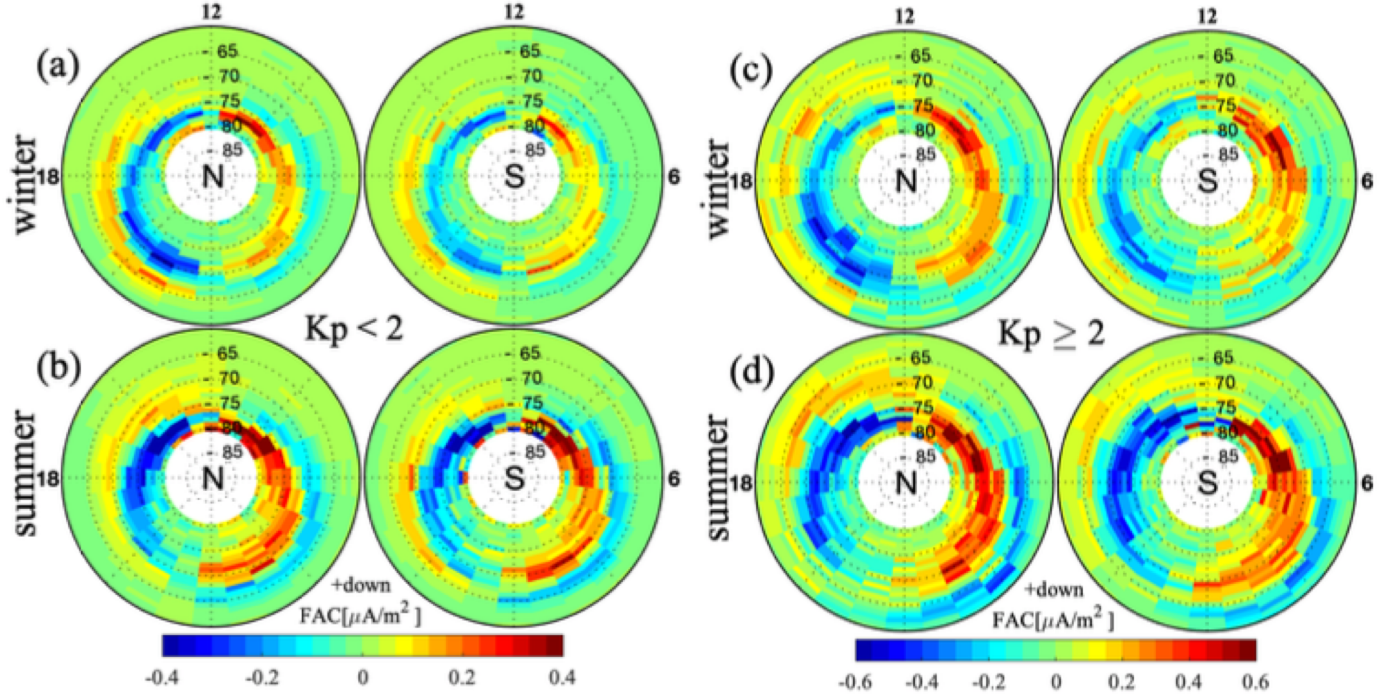


Fig: Distribution of median FAC density for Kp <2 and Kp ≥ 2.

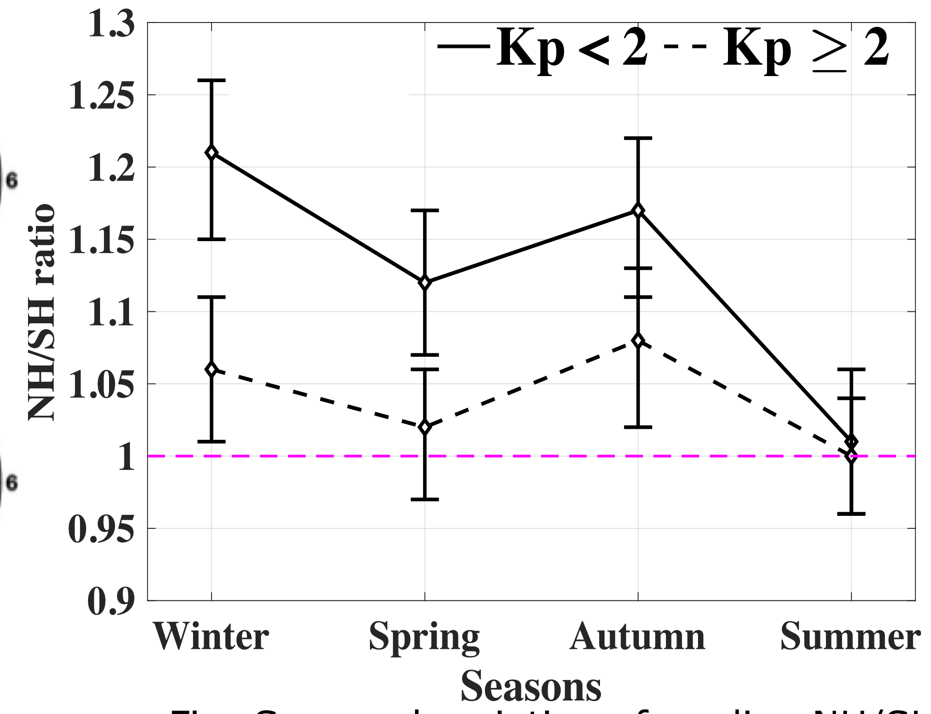


Fig: Seasonal variation of median NH/SH

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 hemispheric asymmetry in winter and autumn for both Kp conditions
- Larger NH/SH ratio for low Kp than high Kp (except for summer)

Kp and seasonal dependence of asymmetry in CF-current

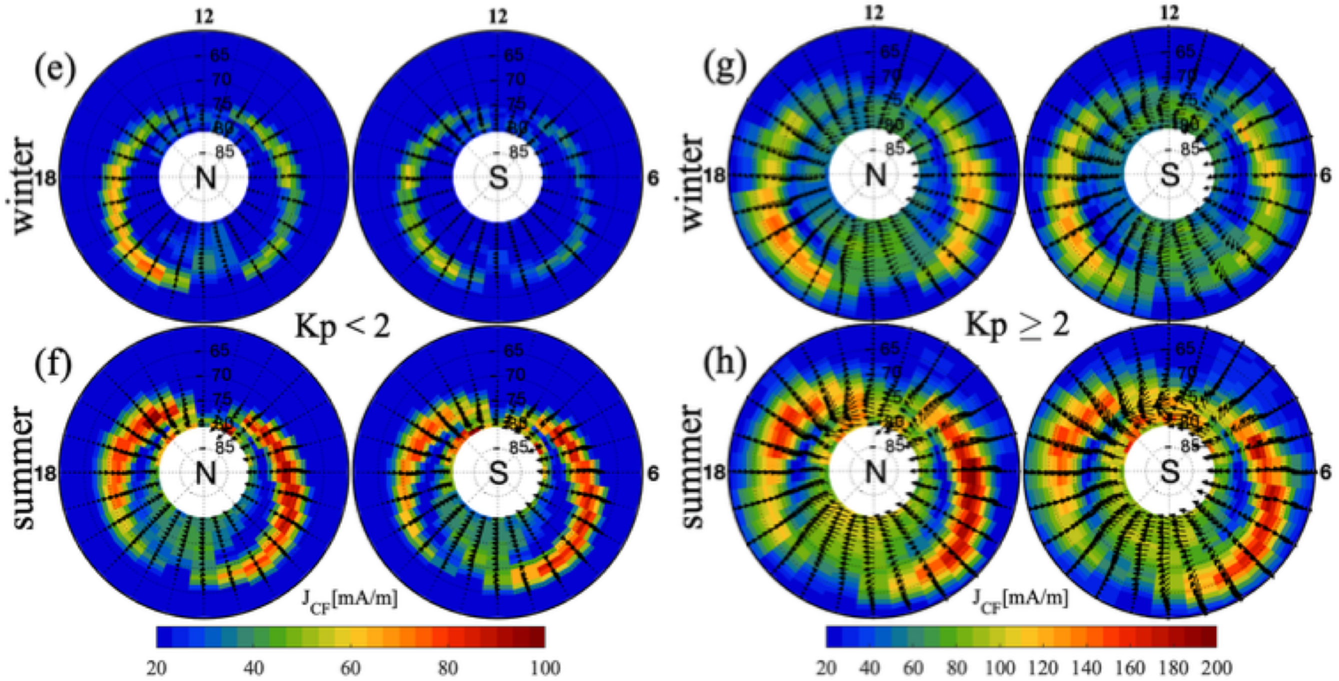


Fig: Distribution of median CF current density for Kp <2 and Kp ≥ 2

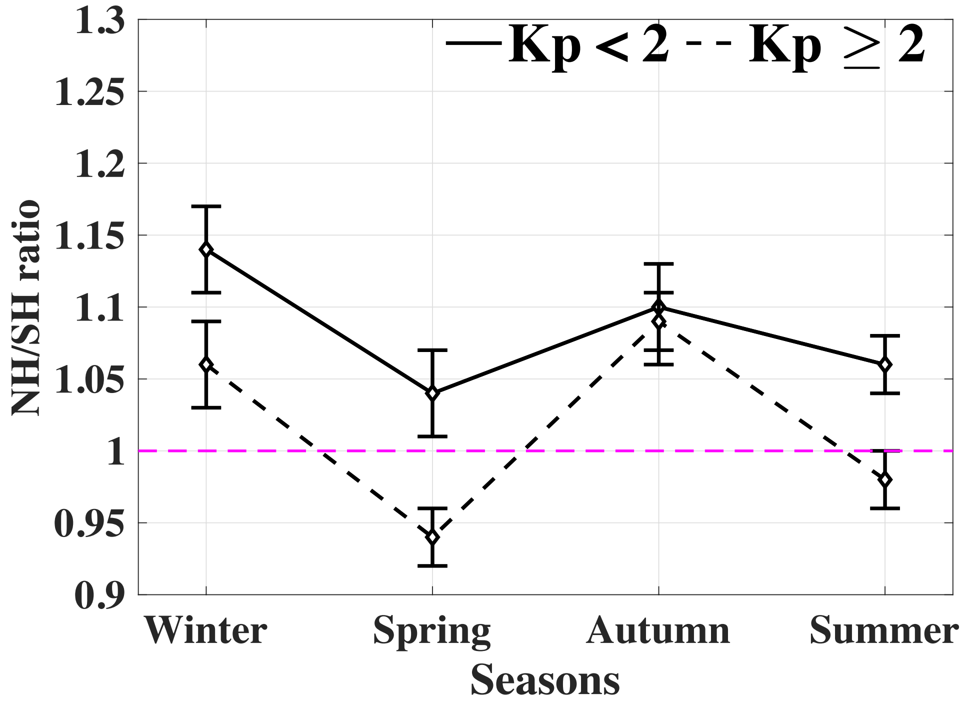


Fig: Seasonal variation of median NH/SH

NH/SH ratio

Kp	winter	spring	autumn	Summer
<2	1.14 ± 0.03	1.04± 0.05	1.10 ± 0.05	1.06 ± 0.05
≥2	1.06 ± 0.03	0.94± 0.02	1.09 ± 0.03	0.98 ± 0.02

- Largest hemispheric asymmetry in winter (low Kp) and autumn (low and high Kp)

Kp and seasonal dependence of asymmetry in DF-current

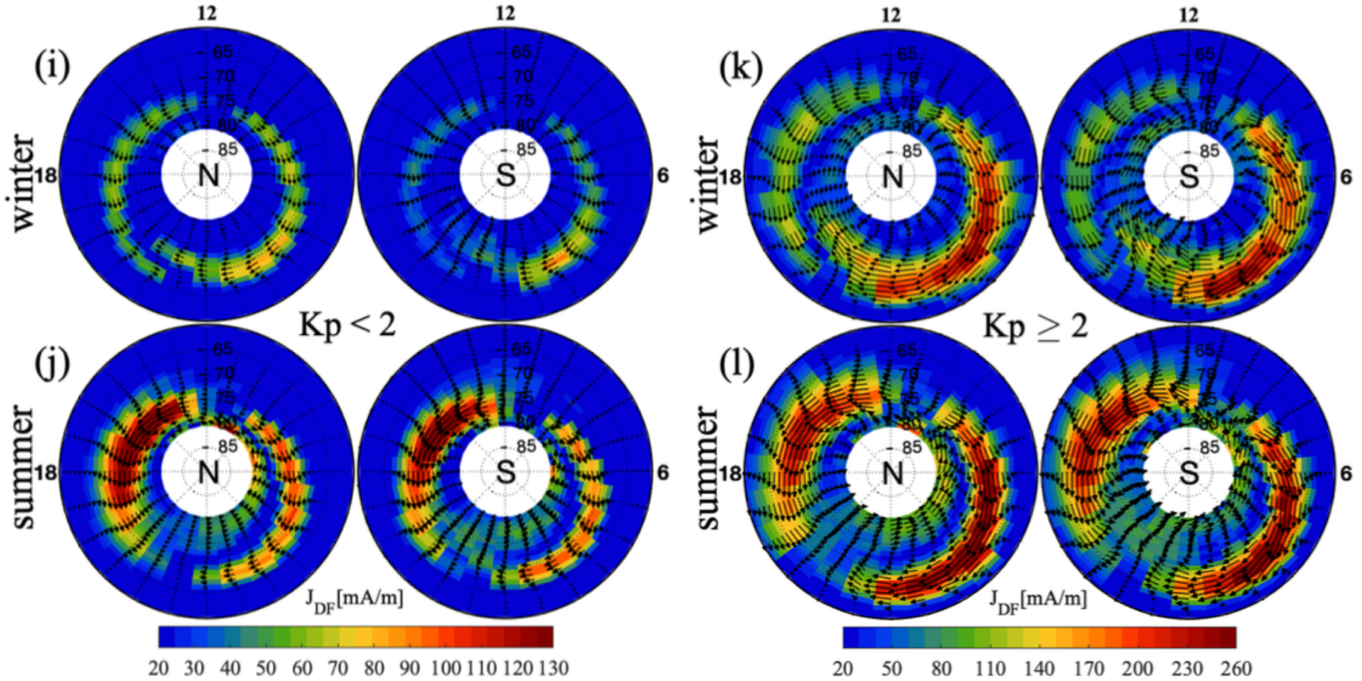


Fig: Distribution of median FAC density for Kp <2 and Kp ≥ 2

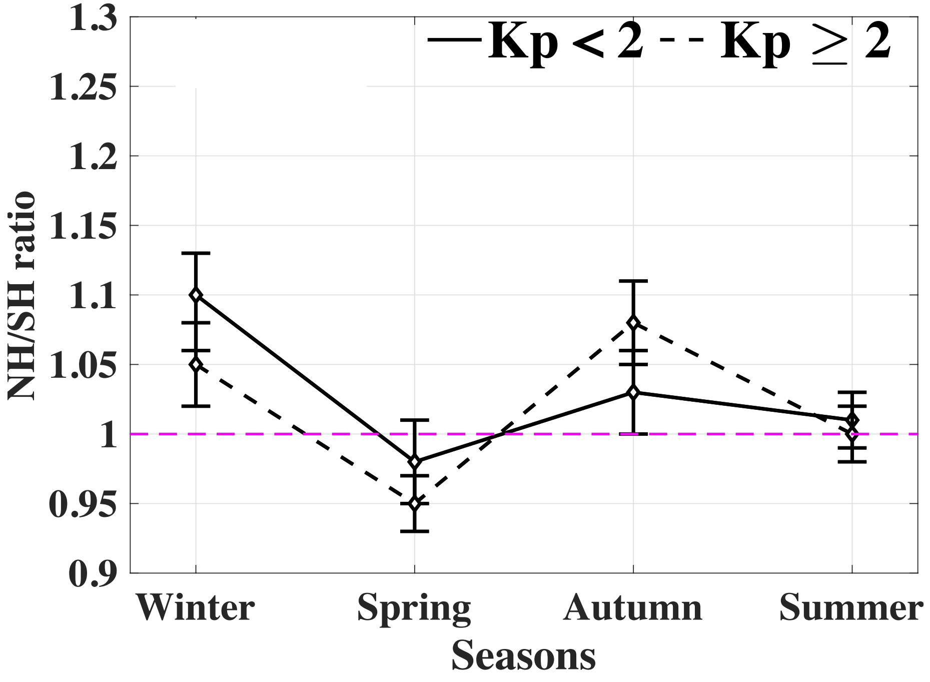


Fig: Seasonal variation of median NH/SH

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 hemispheric asymmetry in winter (low Kp) and in autumn (high Kp)

Conductances from IRI model

- Can the ionospheric background conductivity explain the observed current asymmetry?
  - ➢ Conductances for geomagnetically quiet conditions from the IRI model

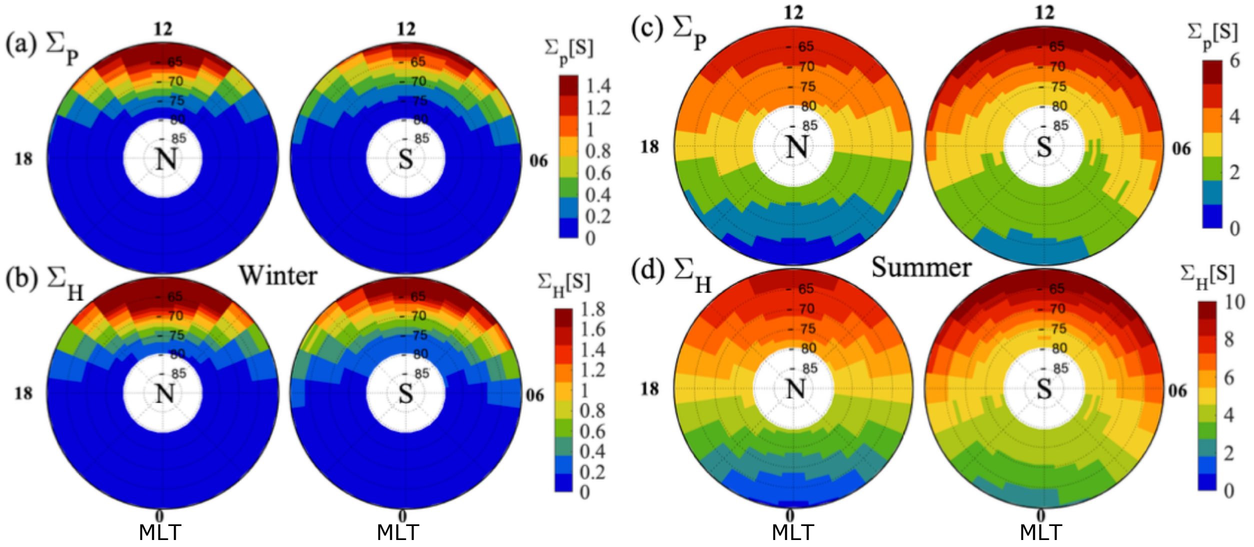


Fig: Distribution of conductance averaged over 00-24 UT

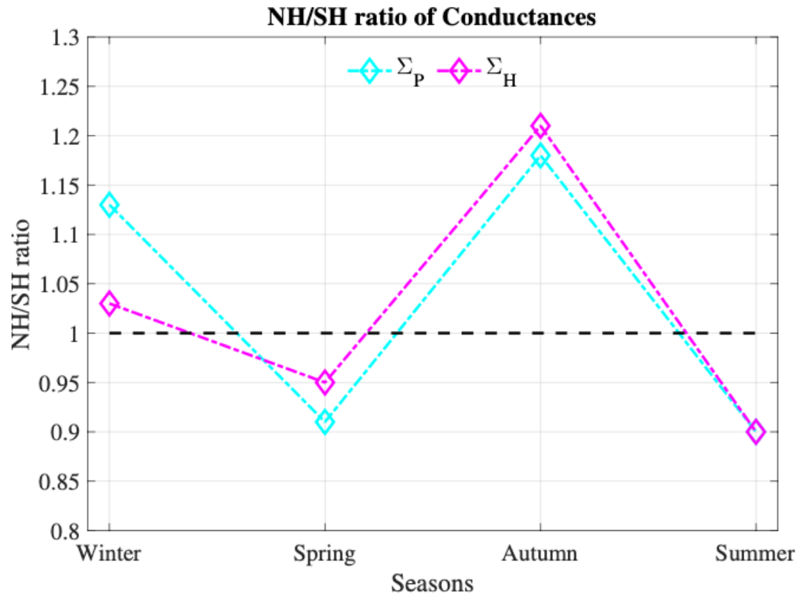


Fig: NH/SH ratios of average conductances

- 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.
  - ➢ Nighttime conductances too small to support significant currents
  - ➢ No auroral oval is produced by IRI, only solar-induced conductances

Summary and conclusions

- Statistical study on the effect of seasons on the asymmetry in the auroral currents during $Kp<2$ and $Kp \geq 2$ from 5 years of Swarm magnetic data
- We find larger NH/SH asymmetry during winter and autumn than summer and spring.
- For $Kp < 6^{+}$, the NH/SH ratio for FACs in winter, autumn, spring and summer are 1.17 ± 0.05, 1.14 ± 0.05, 1.07 ± 0.04 and 1.02 ± 0.04, respectively.
- The largest asymmetry is observed during low Kp winter, when the excess in the NH currents is $21 \pm 5\%$ in FAC, $14 \pm 3\%$ in curl-free (CF), and $10 \pm 3\%$ in divergence-free (DF) current.
- We also find that evening sector (13-24 MLT) contributes more to the high NH/SH ratio than the morning (01-12 MLT) sector.
- Solar-induced conductivity from IRI explains only a small part of the hemispheric asymmetry.
- The physical mechanisms producing the hemispheric asymmetry are not presently understood.
- In our next paper, we will address the effect of solar wind and IMF on the hemispheric asymmetry.