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Statistical study of field-aligned currents and equivalent currents based on Swarm constellation

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Introduction

The ionospheric currents comprise Pedersen currents, Hall currents, and Field-aligned currents (FACs) at high latitude.

The first representative FAC distribution was reported by using the magnetometer measurements from Triad satellite, in which FAC follows a double ring pattern. Region 1 (R1) currents are located in the poleward, flowing into the ionosphere on the dawn side and out on the dusk side. Region 2 (R2) currents are located a few degrees equatorward flowing in the opposite direction to R1. Previous observations have shown that IMF orientation and seasonal differences have influences on the distribution of FAC.

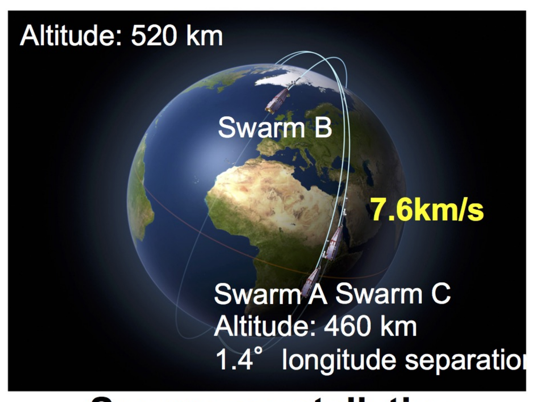
Hall currents are the most intensive in the ionosphere. As standard pattern they form the auroral electrojets flowing anti-sunward both on the dawn and dusk sides. Sunward return currents are flowing over the polar cap. Traditionally, Hall currents are studied from ground-based observations. But they can derive only equivalent currents.

The relationship between high-latitude FACs and the Hall electrojets has been studied by some works though it is not conclusive. ESA's constellation mission, Swarm provides us the opportunity to simultaneously study both the FAC and equivalent current in the ionosphere.

The Swarm and IMF datasets

◆ Data interval:
17 April 2014 --17 April 2017

◆IMF and solar wind data:
1min resolution OMNI data



Swarm constellation

✓ SWARM FAC estimate

(Lühr et al. 2015, Wang et al. 2005)

➢ **Vertical current density:**

$$j_z = \frac{1}{\mu}\oint B_H \cdot dl$$

➢ **Current along the field line:**

$$j_{\parallel} = \frac{j_z}{\sin I}$$

I is the magnetic inclination

CHAOS Model:
core field,
Crustal field,
external field

Merging electric field：(Newell et al. [2007])

$$E_m = \frac{1}{3000} V_{sw}^{\frac{4}{3}} \left(\sqrt{B_y^2 + B_z^2}\right)^{\frac{2}{3}} \sin^{\frac{8}{3}}\left(\frac{\theta}{2}\right)$$

Estimating equivalent current

✓ Estimating equivalent current

(Ref: Olsen 1996; Ritter et al., 2004)

Infinite line current assumption

$$b_x = -\frac{\mu_0 I}{2\pi}\frac{h}{x^2+h^2},$$

$$b_z = -\frac{\mu_0 I}{2\pi}\frac{x}{x^2+h^2}$$

$$\Delta F = |\boldsymbol{B}+\boldsymbol{b}| - |\boldsymbol{B}|$$

$$\Delta F = \frac{\boldsymbol{B}\cdot\boldsymbol{b}}{|\boldsymbol{B}|}$$

I

110km Altitude

$$\Delta F = G \cdot I$$

$$I = (G^T A\, G)^{-1} G \Delta F$$

$|B+b|$ is the measured scalar field and $|B|$ is the unperturbed magnetic field represented by CHAOS model.

The intensity of each of 160 line currents considered for the modelling can be derived from an inversion of the observed field residuals using a least-square-fitting approach.

Ring current effect
Removal of trend (zero at 50°)

Distribution of field-aligned currents and equivalent currents

FAC

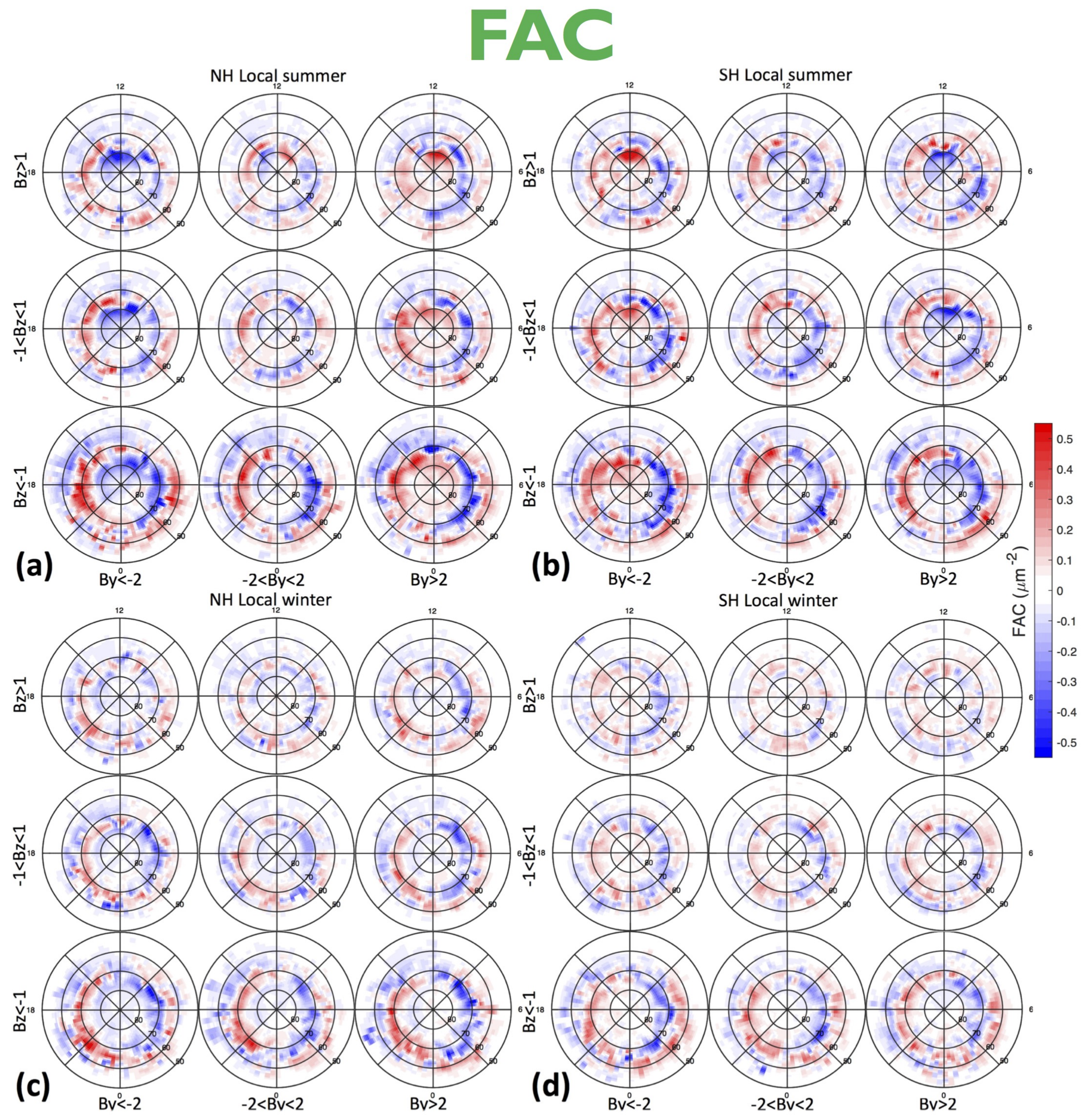


Figure 1. FAC distributions in the (top) local summer and (bottom) local winter (left) Northern Hemisphere and (right) Southern Hemisphere.

Equivalent Current

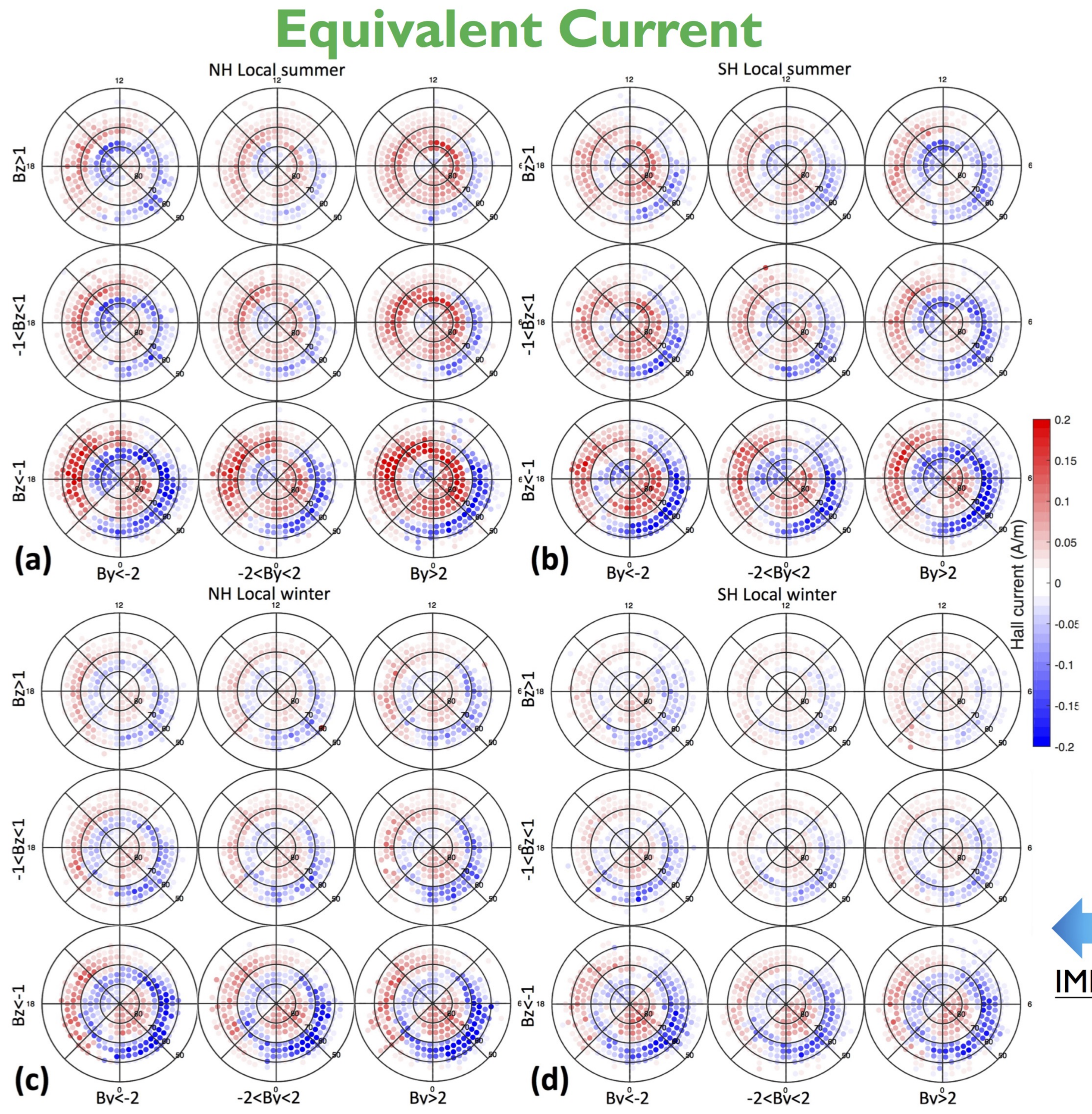
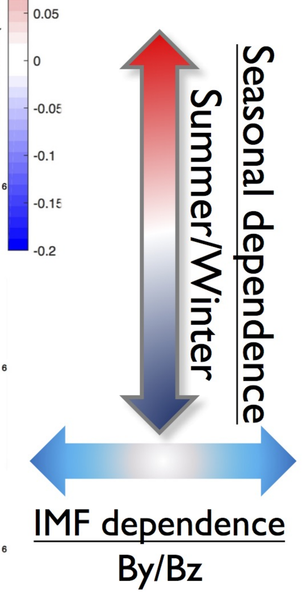


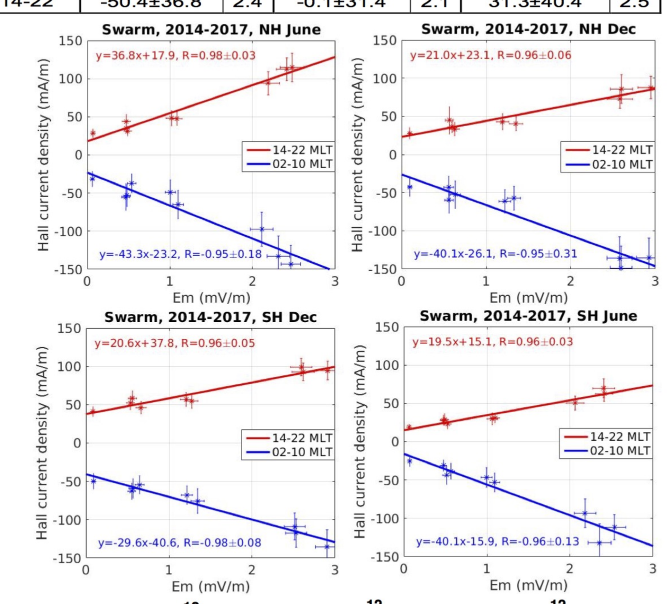
Figure 2. Same to Figure 1 but for equivalent current distribution

One Table example

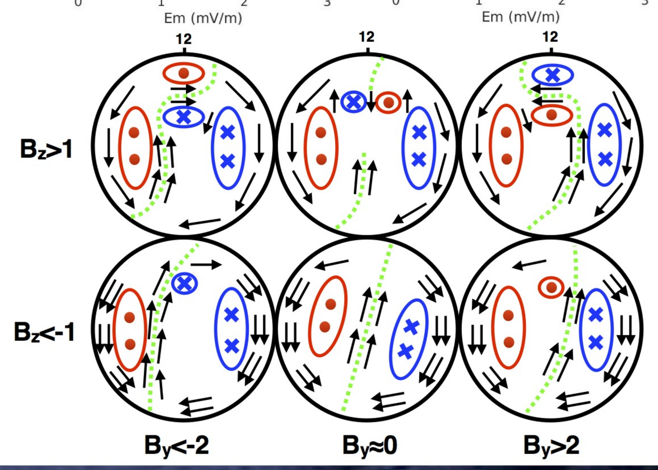
NH Local summer		MLT	$B_y<-2$ J_{Hall}	$B_y<-2$ E_m	$-2<B_y<2$ J_{Hall}	$-2<B_y<2$ E_m	$B_y>2$ J_{Hall}	$B_y>2$ E_m
$B_z>1$	PC	10-14	-20.6±52.5	0.6	18.9±26.8	0.1	53.9±46.7	0.5
		22-02	1.7±13.5	0.5	22.4±12.5	0.1	56.9±12.4	0.4
	AZ	10-14	17.2±10.9	0.6	16±8.3	0.1	12±9.8	0.5
		22-02	-13.6±17.5	0.5	-11.5±12.1	0.1	-12.8±20.7	0.5
	PC	02-10	-10.5±21.6	0.5	17.6±18.9	0.1	53.1±31.4	0.5
		14-22	-21.6±36.3	0.5	9.9±23.2	0.1	38.6±20.1	0.5
$-1<B_z<1$	PC (60° < PC < 70°)	10-14	-10.7±55.6	1.0	27.8±29.2	0.5	63.4±53.2	1.1
		22-02	11.2±17.1	1.0	32.1±14	0.5	60.4±15.4	1.0
	AZ (70° < AZ)	10-14	25.6±13.9	1.1	17.8±10.3	0.5	15.3±8.8	1.1
		22-02	-25.7±22.9	1.0	-18.5±20.1	0.5	-23.4±27.3	1.0
	PC	02-10	-6.9±30.3	1.0	19.3±23	0.5	55.6±38.2	1.1
		14-22	-25.2±39.9	1.0	18±28.8	0.5	43.6±31.4	1.1
$B_z<-1$	PC	10-14	-44.3±71.5	2.4	27.4±42.3	2.2	83.8±70.3	2.8
		22-02	35.6±25.2	2.4	57.7±18.5	2.1	91.6±25.6	2.4
	AZ	10-14	29.1±20.8	2.4	27.7±20.2	2.1	20.8±28.8	2.9
		22-02	-60.9±30.5	2.5	-45.6±33.6	2.1	-60.2±41.2	2.6
	PC	02-10	19.1±53.7	2.3	42.2±38.2	2.1	107±39.2	2.4
		14-22	-50.4±36.8	2.4	-0.1±31.4	2.1	31.3±40.4	2.5



The relationship between equivalent current density and E_m



Schematic drawing of equivalent current



Summary

1. The FAC patterns are derived from the dual-spacecraft method, which provides more reliable results in particular at polar cap latitudes. Overall, the obtained FAC distribution is consistent with previous results.
2. The auroral electrojets are closely controlled by the solar wind input represented by the merging electric field. The eastward electrojet on the dawnside shows a seasonal dependence reflecting the difference in ionospheric conductivity. Conversely, the westward electrojet does not change much over the seasons or on different IMF B_y orientations.
3. The intensity of polar cap return currents is directly proportioned to ionospheric conductivity. The current flow is not homogenously distributed over the polar cap, it is strongly dependent on the IMF B_y orientation.
4. In the noon sector the direction of equivalent currents is highly dependent on IMF B_y orientation. In case of positive IMF B_z equivalent currents are related to the *NBZ* system, which is practically absent during winter in the dark hemisphere. For negative IMF B_z conditions more intense equivalent currents appear around noon with the same dependence on IMF B_y. They are related to the *DPY* system.
5. Equivalent currents around the midnight sector are related to substorm activity. Their intensity is closely controlled by magnetic activity. They show little dependence on season when normalized to a fixed level of magnetic activity.

More ☞ ***New features of ionospheric horizontal current are revealed in our recent studies.***

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