Electrodynamics of field-aligned currents in the magnetosphere-ionosphere system

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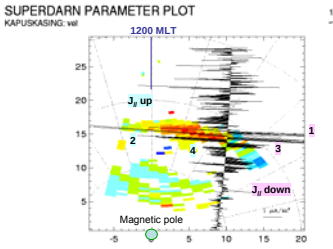
Structure of meso-scale currents

1. Low-altitude cusp: closure of the parallel currents associated with reconnected flux tube



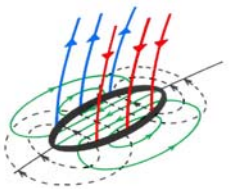
Observations

- signature of sporadic reconnection (FTE)

- conjunction between **Ørsted** (parallel currents) and **SuperDARN** (convection)

- The superposition of the Ørsted orbit over the SuperDARN radial velocity map measured at the same time shows that the small-scale currents are co-located with the convection flow burst

- The small-scale current sheets are labelled 1 to 4, and only the currents 3 and 4 are directly linked to the flow burst



Model of Flux Transfer Event (FTE) including the closure of parallel currents by ionospheric Pedersen currents across the reconnected flux tube

Analyse of the electric circuit associated with magnetic flux tube connected to the interplanetary medium

It is shown that this circuit is completely autonomous and independent of the larger-scale parallel current structures

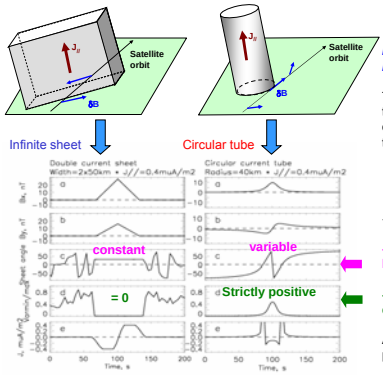
Conclusion: the pair (3-4) of parallel currents closes in the ionospheric E layer by a Pedersen current flowing across the flux tube

Closure current (SuperDARN)
$J_P = \Sigma_P E = 0{,}225$ A.m^{-1}

Parallel currents (3) and (4) (Ørsted)
$J_{//+} = J_{//-} = 0{,}18$ A.m^{-1}

Ref: Marchaudon et al., *Geophys. Res. Lett.*, 31, L09809, 2004.

2. All altitudes: discriminate between sheet-like and tube-like parallel currents



Method based on the analysis of the covariance matrix of the magnetic signal

The usual "infinite current sheet hypothesis" used in the determination of parallel currents along one SC orbit, is not always valid. We have defined a method to test its validity

→ Two pertinent parameters:

- direction of the eigenvector associated with the largest eigenvalue = *polarisation vector*

- ratio between the intermediate and the largest eigenvalues = *variance ratio*

Application is made to parallel currents associated with plasma injections in the cusp observed by **Cluster**

Ref: Marchaudon et al., *Ann. Geophys.*, 24, 3391-3401, 2006.
Ref: Marchaudon et al., *Ann. Geophys.*, 27, 1251-1266, 2009.

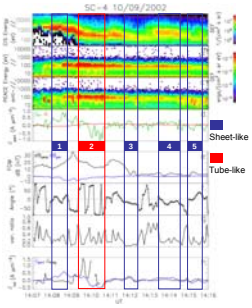
Application to cusp injections observed by Cluster at mid-altitude

- Cusp plasma injections from the magnetosheath into the magnetosphere are characterised by particle fluxes with energies below 1 keV for ions and a few 100 eV for electron. Cluster is in a string of pearl configuration

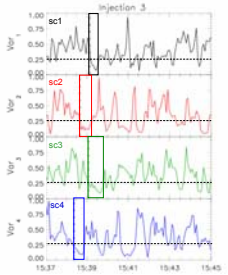
- FAC calculation from magnetic data and from particle data.

Red : Tube-like current structures characterised by a high variance ratio and a variable sheet direction. Magnetic and particle currents are not consistent (2).

Blue : Sheet-like current structures characterised by a small variance ratio and a stable sheet direction. Magnetic and particle currents are generally consistent (3,4,5), apart when large velocity drift of injection structures (1) for which magnetic current is still not accurately calculated.



Magnetic variance – **Cluster** 20/02/2005



Application to cusp injections observed by Cluster at high-altitude

- Same characteristics of plasma injections than in previous event but at higher altitude, with Cluster in tetrahedral configuration

- Low variance ratio at the beginning of each injection
= Upstream side magnetically well defined

- Variable variance ratio during the rest of each injection
= Downstream side more turbulent

- Direction of polarisation vectors differs slightly between the four Cluster spacecraft. Fit with a circle in the plane normal to **B**

Forward front of injection: concave, with a radius of 0.38 R_E, suggesting a bean-like structure

3. High-altitude cusp: validate FAC determination by single-SC method

FAC from curlometer and from single-SC method at Cluster at high altitude

- Same profiles for each injection:
pair of opposite FAC (downward/upward)

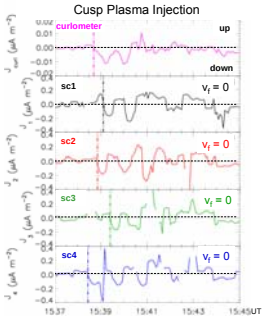
- Different extensions and intensities of sub-structures between SC

- Curlometer FAC intensity << 1-SC FAC intensity
→ $V_t = 0$

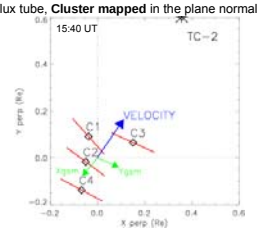
- With $V_t \neq 0$ (from 4-SC timing technique):
intensity = ~ 0.01 - 0.015 µA.m^{-2}, now consistent between both methods

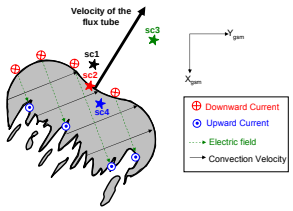
Ref: Marchaudon et al., *Ann. Geophys.*, 27, 1251-1266, 2009.

Parallel currents – **Cluster** 20/02/2005
Cusp Plasma Injection



Quasi-linear polarisation on the curved front side of reconnected flux tube, **Cluster mapped** in the plane normal to **B**





New perspectives provided by SWARM

1. SWARM (A,B) curlometer technique and SuperDARN convection applied to auroral electrodynamics

- Direct use of Ampere's law free of the infinite current sheet hypothesis:

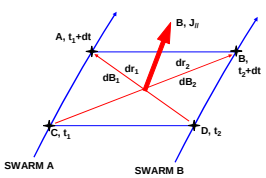
$$\mathbf{J}_{//} = \frac{\vec{\nabla} \times \mathbf{b}}{\mu_0}$$

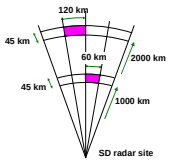
- Assuming only the stationarity of the parallel currents over the period of measurement (t -> t+dt):

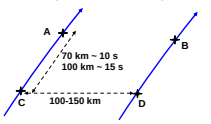
$$\mathbf{J}_{//} = \frac{\delta \mathbf{B}_1 . \delta \vec{r}_2 - \delta \mathbf{B}_2 . \delta \vec{r}_1}{\mu_0 (\delta \vec{r}_1 \times \delta \vec{r}_2).(\mathbf{B}/|\mathbf{B}|)}$$

- By suppressing the need for the infinite current sheet hypothesis, SWARM offers a unique opportunity for a quantitative test of the discrimination method based on the variance analysis

- Parallel currents by curlometer (SWARM A,B) : ***level 1B product***





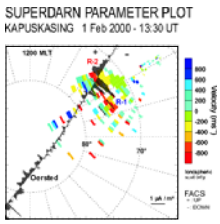


2D reconstruction of the meso-scale auroral electrodynamics (FTEs, TCVs, auroral arcs…)

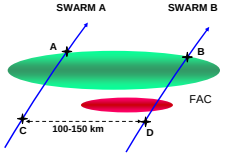
- 2D FAC with SWARM (A,B)

- 2D E-field pattern with SuperDARN

- Same spatial resolutions for SWARM (A,B) and SuperDARN, which fit well with the typical scales of meso-scale current and convection structures



2. FAC coherent spatial scale thanks to SWARM (A,B)

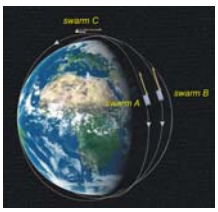


Fine structure of parallel currents

- discriminating between filamentary and sheet structures

- defining the smaller spatial scale for which both spacecraft observe the same structures

3. Spatial and temporal evolution of large-scale FAC and convection pattern thanks to SuperDARN and SWARM (A,B,C)



Symmetry and asymmetry of large-scale FAC and convection pattern

- dayside/nightside pattern

- dawnside/duskside pattern wrt to IMF

Time evolution of large-scale structures

-SWARM C in the same local time sector, and trading or leading SWARM (A,B) by several min

- 2D convection map from SuperDARN (polar cap and auroral zones)