Field-aligned currents in the Earth's magnetosphere

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Acknowledgments

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Outline

1. Introduction

2. Method: infinite current sheet

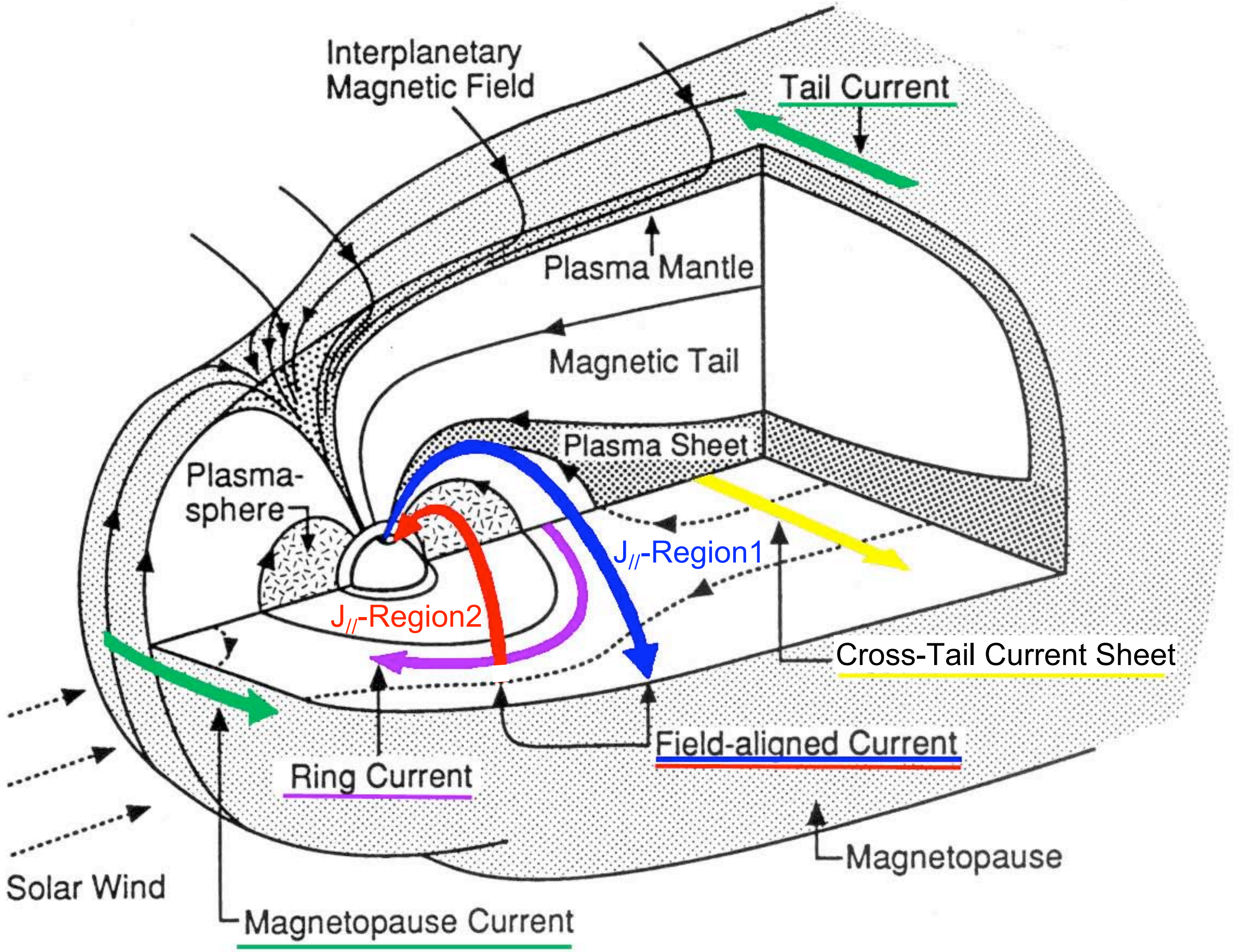
3. Historical background

4. Results
   - Large-scale currents during geomagnetic storm
   - Electrodynamics of small-scale structures
   - Test of the infinite current sheet hypothesis

5. Conclusion and perspectives

Introduction

The large-scale convection and currents in the Earth's magnetosphere



The magnetosphere field-aligned currents

2 main systems of field-aligned currents:

1. $J_{//}$-Region 1 provides coupling between the solar wind and the magnetosphere-ionosphere system (direct in the dayside and indirect in the nightside during substorm activity)

2. $J_{//}$-Region 2 provides coupling between the inner magnetosphere and the ionosphere

Important Questions

• Changes of the large-scale field-aligned currents (position/intensity) with respect to solar wind conditions

• Electrodynamics of small-scale structures (reconnected flux tubes in the dayside, auroral arcs in the nightside)

• Discrimination between sheet and tube patterns for meso-scale structures such as cusp injections

Method

Derivation of the parallel currents from measurements along the orbit of a single satellite

At low-altitude (Ørsted, Champ, FAST): $|v_{sc}| >> |v_{sh}|$

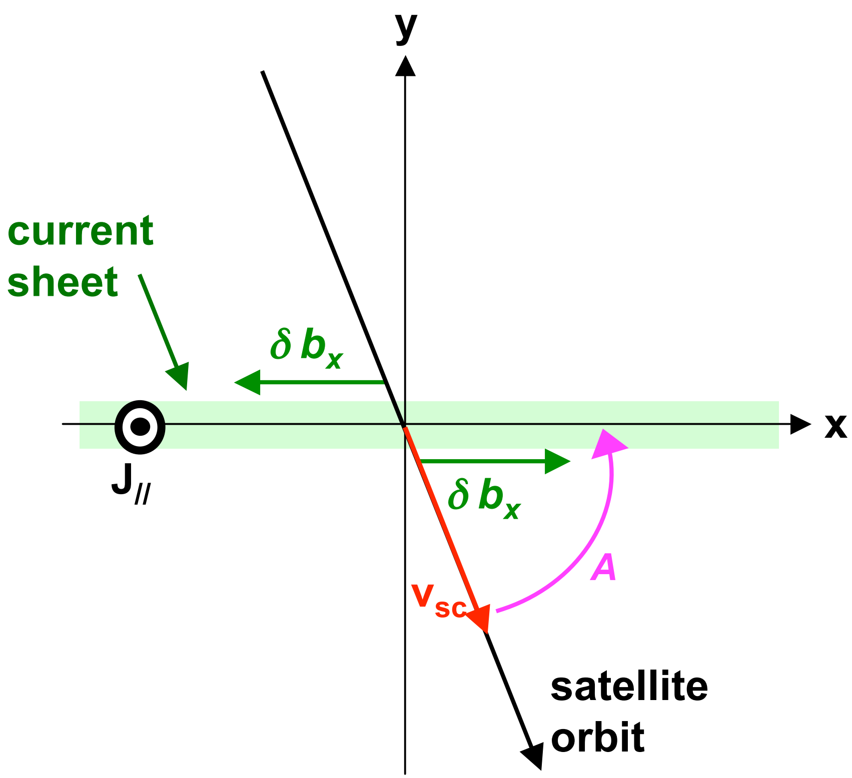
1. Substracting the Earth's internal magnetic field: $\mathbf{b} = \mathbf{B}_{measured} - \mathbf{B}_{model}$

2. Assumption: currents distributed in infinite uniform sheets

3. Direction of the current sheet given by the orientation of **b**

4. Intensity of the parallel current:

$$\mathbf{J}_{//} = \frac{\vec{\nabla} \times \mathbf{b}}{\mu_0} = -\frac{1}{\mu_0}\frac{\partial b_x}{\partial y}\mathbf{e}_z = -\frac{1}{\mu_0}\frac{\partial b_x}{\partial t}\frac{1}{v_n}\mathbf{e}_z$$



with : $v_n = v_{sc} \sin A$

5. Limitation:

- the method fails if the orbit is parallel to the current sheet

Derivation of the parallel currents from measurements along the orbit of a single satellite

At mid-altitude (Cluster at perigee) : $|v_{sc}| \sim |v_{sh}|$

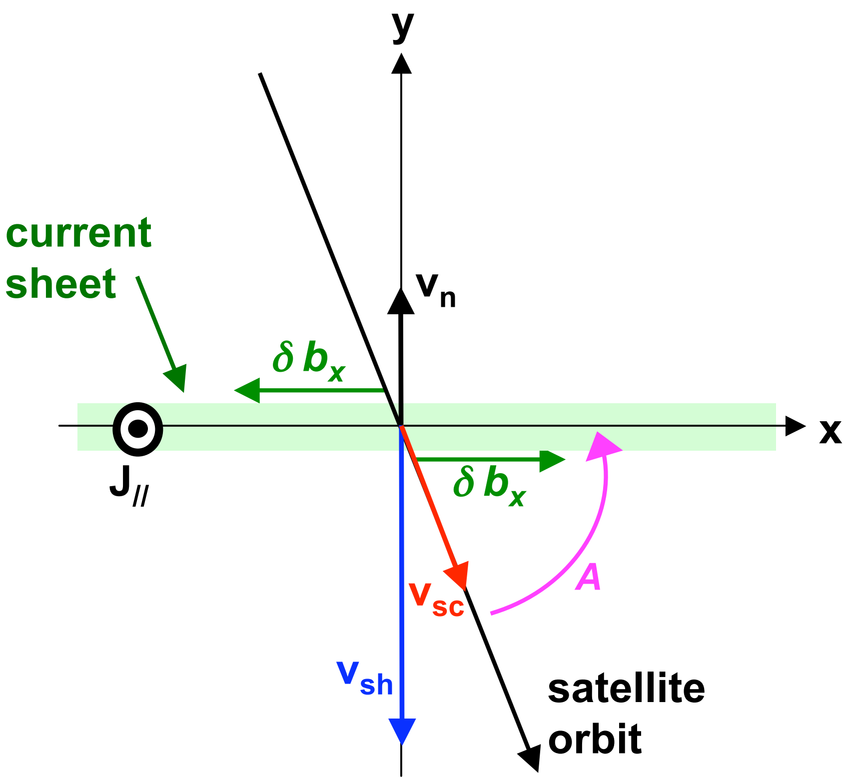
1. Substracting the Earth's internal magnetic field: $\mathbf{b} = \mathbf{B}_{measured} - \mathbf{B}_{model}$

2. Assumption: currents distributed in infinite uniform sheets

3. Direction of the current sheet given by the orientation of **b**

4. Intensity of the parallel current:

$$\mathbf{J}_{//} = \frac{\vec{\nabla} \times \mathbf{b}}{\mu_0} = -\frac{1}{\mu_0}\frac{\partial b_x}{\partial y}\mathbf{e}_z = -\frac{1}{\mu_0}\frac{\partial b_x}{\partial t}\frac{1}{v_n}\mathbf{e}_z$$



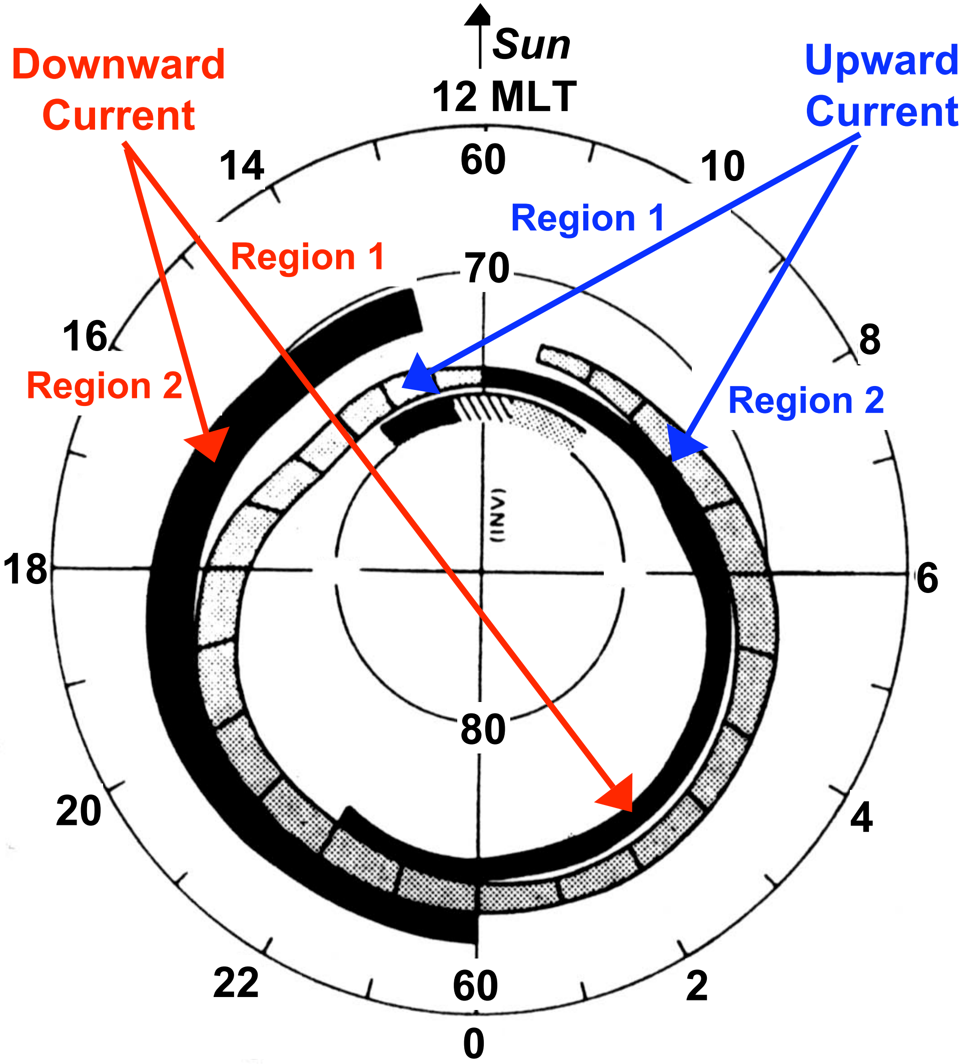
with : $v_n = v_{sc} \sin A - v_{sh}$

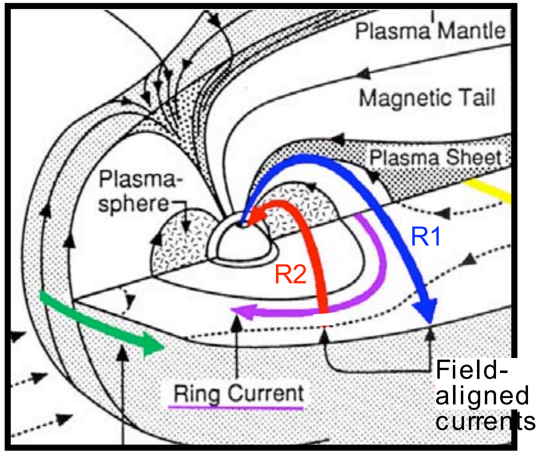
5. Limitations:

- v_{sh} unknown
- polarity and amplitude of $J_{//}$ depend of v_n

Historical background

Initial determination of the large-scale field-aligned currents pattern

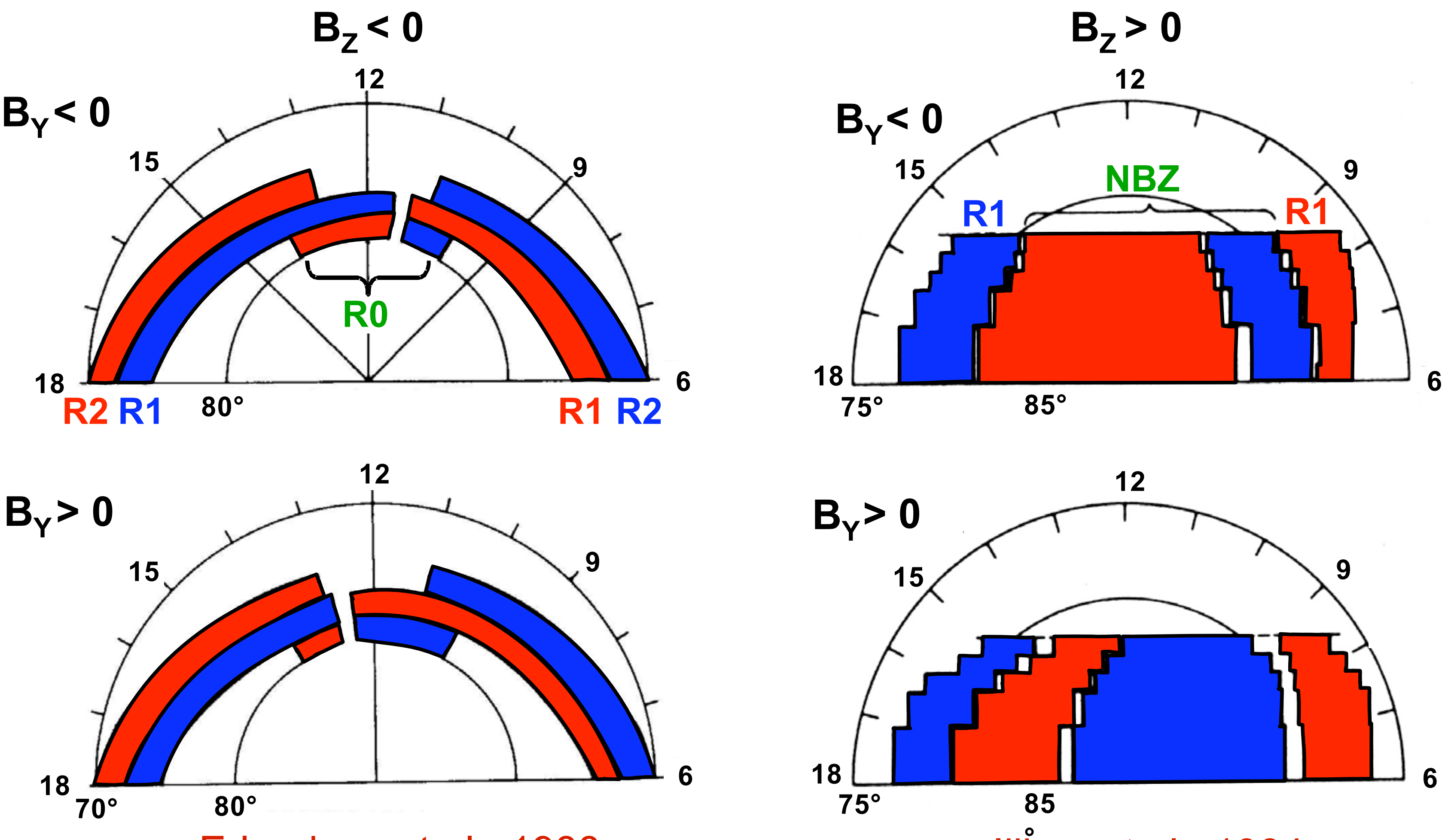




- First statistical study by Iijima and Potemra (1976) from the TRIAD satellite
- First observation of the $J_{//}$-Region 1 and $J_{//}$-Region 2 pattern
- Statistical study for all IMF conditions (similar results for IMF-Bz < 0 conditions)

Currents into ionosphere - downward
Currents away from ionosphere - upward

Dayside large-scale field-aligned currents distribution for different IMF conditions

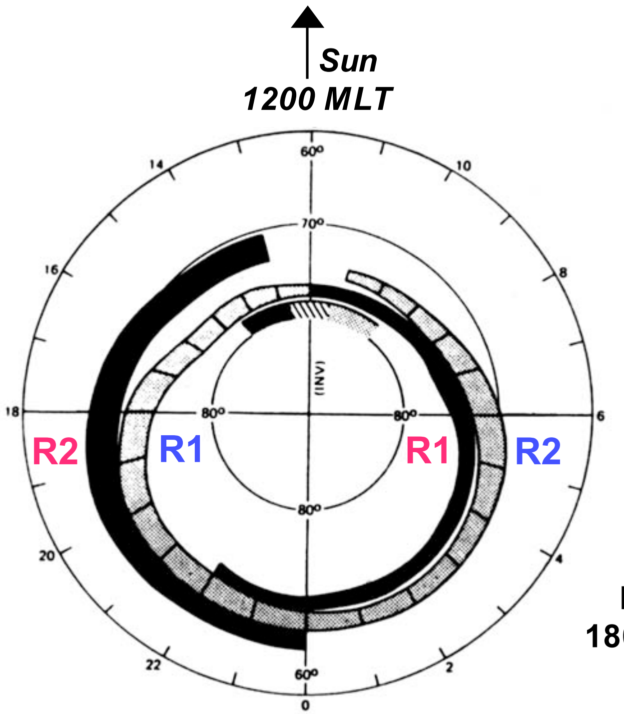


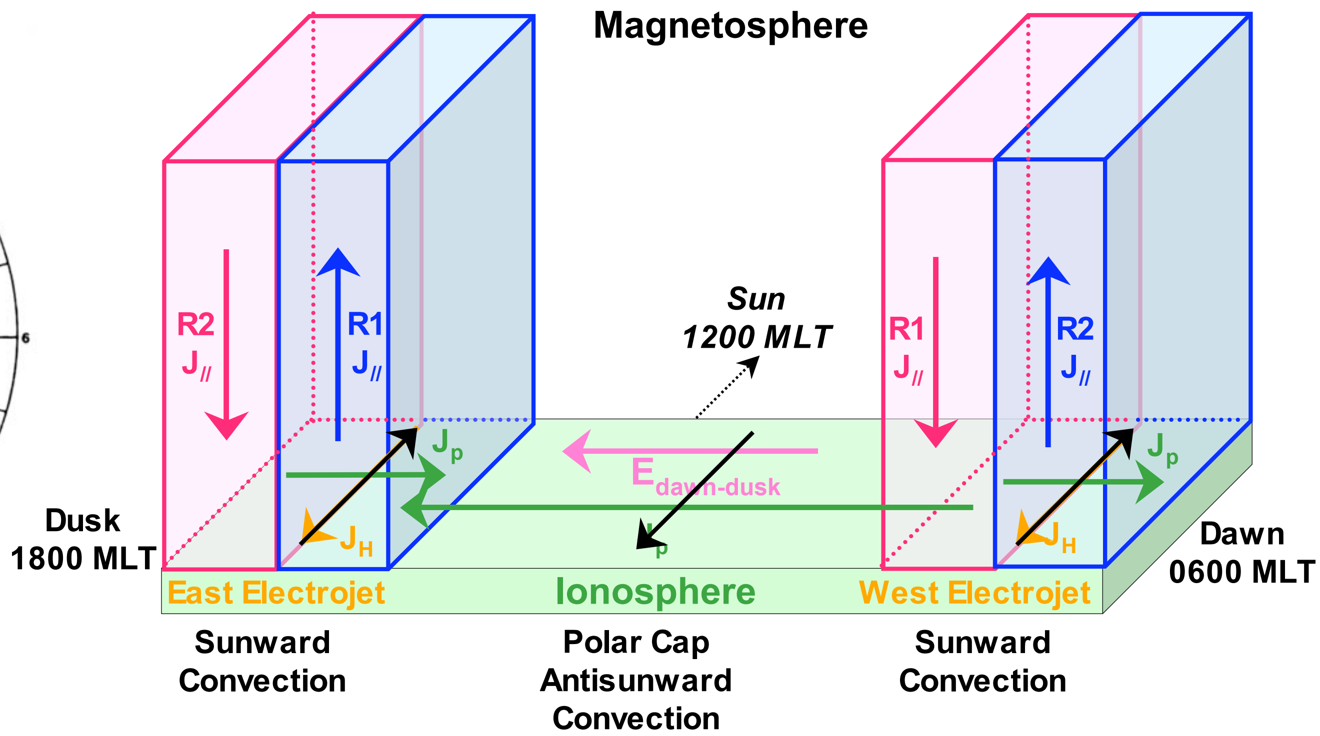
Erlandson et al., 1988
Viking satellite

Iijima et al., 1984
Magsat satellite

Currents into ionosphere - downward
Currents away from ionosphere - upward

Ionospheric closure of the large-scale field-aligned currents



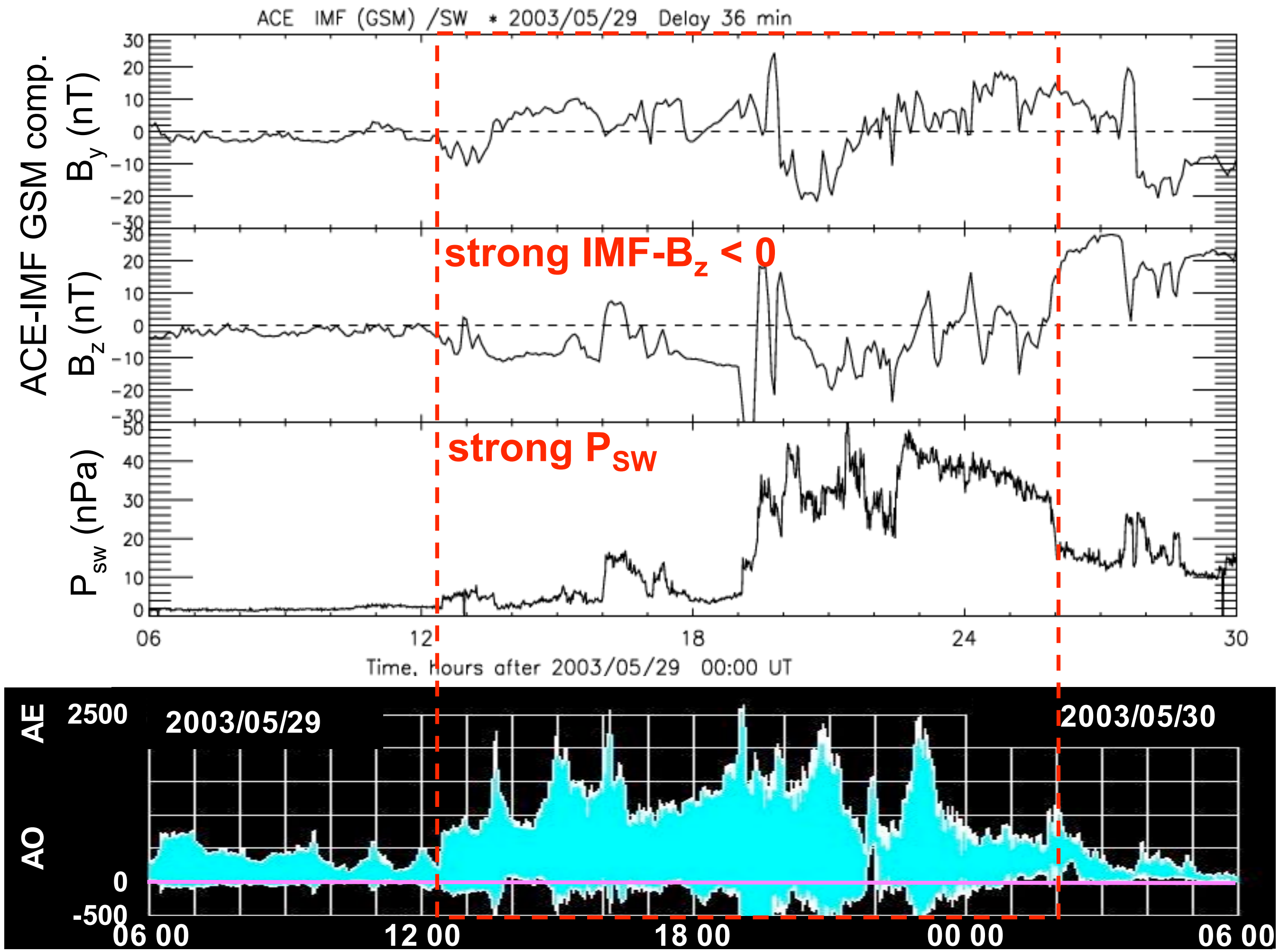


- Ionospheric convection: **E** = - **V** x **B**
- Large-scale field-aligned currents are closed in the lower ionosphere by horizontal Perdersen currents J_P (flowing parallel to the ionospheric convection electric field)
- Hall currents J_H (flowing perpendicular to the ionospheric convection electric field) are also generated by the medium anisotropy

Results (1)
Large-scale field-aligned currents: position and intensity during a geomagnetic storm

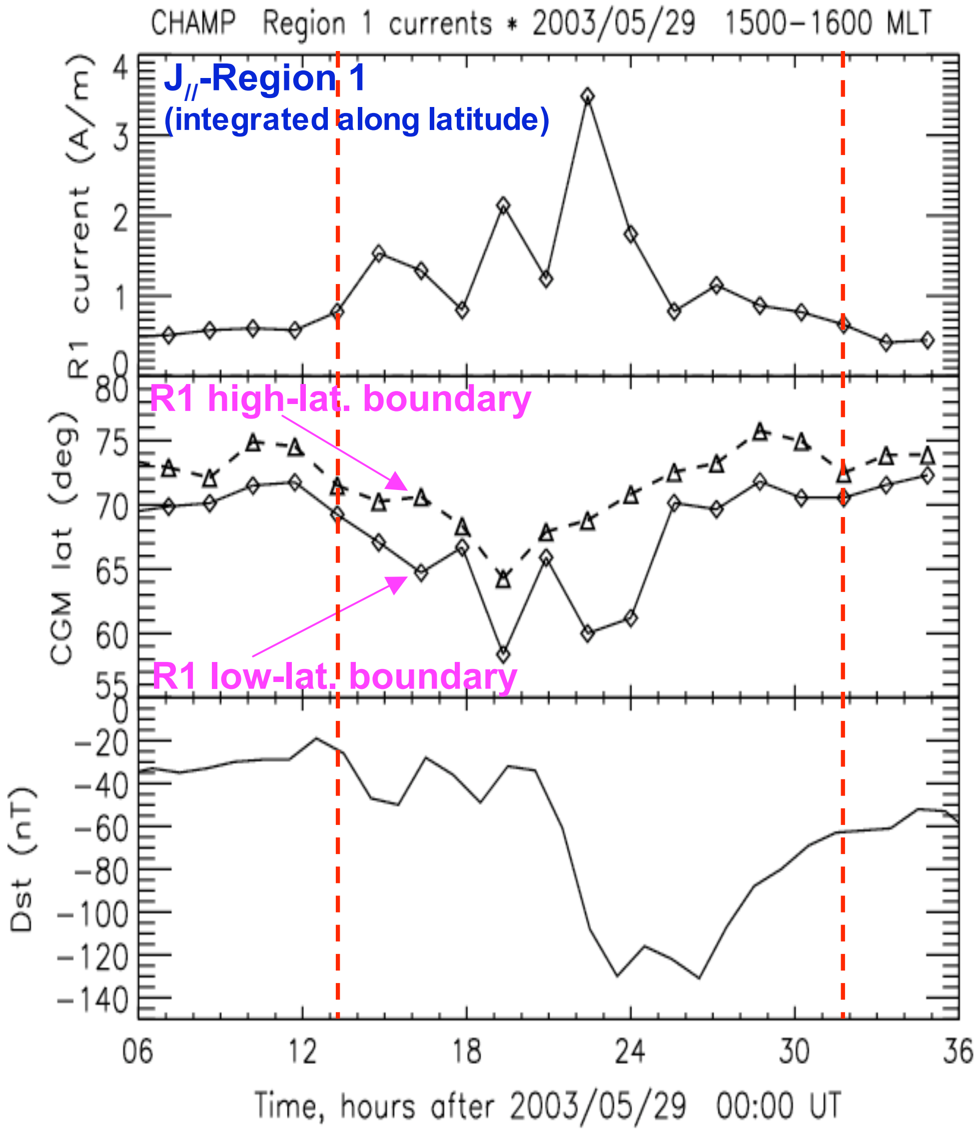
Region-1 of currents as a measure of the solar wind coupling with the magnetosphere during a magnetic storm – 29-30/05/2003

Intense interplanetary conditions



Magnetosphere-ionosphere responses

Region-1 of currents as a measure of the solar wind coupling with the magnetosphere during a magnetic storm – 29-30/05/2003



- Intensity of the $J_{//}$-Region 1 deduced from a series of successive passes of CHAMP in the 1500 MLT sector
- **Factor 7** between FAC intensity during storm and during quiet period

- Location and width of the $J_{//}$-Region 1
- **10-12° equatorward shift** during storm
- **Factor 3** between region width during storm and during quiet period

- Dst index monitoring the magnetopause and ring currents
- **Delay of the Dst response** with respect to the $J_{//}$-Region 1 response

Region-1 of currents as a measure of the solar wind coupling with the magnetosphere during a magnetic storm – 29-30/05/2003

Conclusions

- **$J_{//}$-Region 1 properties during the magnetic storm:**

(13 successive passes of CHAMP from 13:15 UT on May 29 - 07:40 UT on May 30)

  - typical intensity larger than 3,5 A/m
  - associated magnetic perturbations larger than 1000 nT
  - 10-12° motion toward lower latitudes
  - 10° width

→ **Dramatic quantitative changes of $J_{//}$-Region 1**

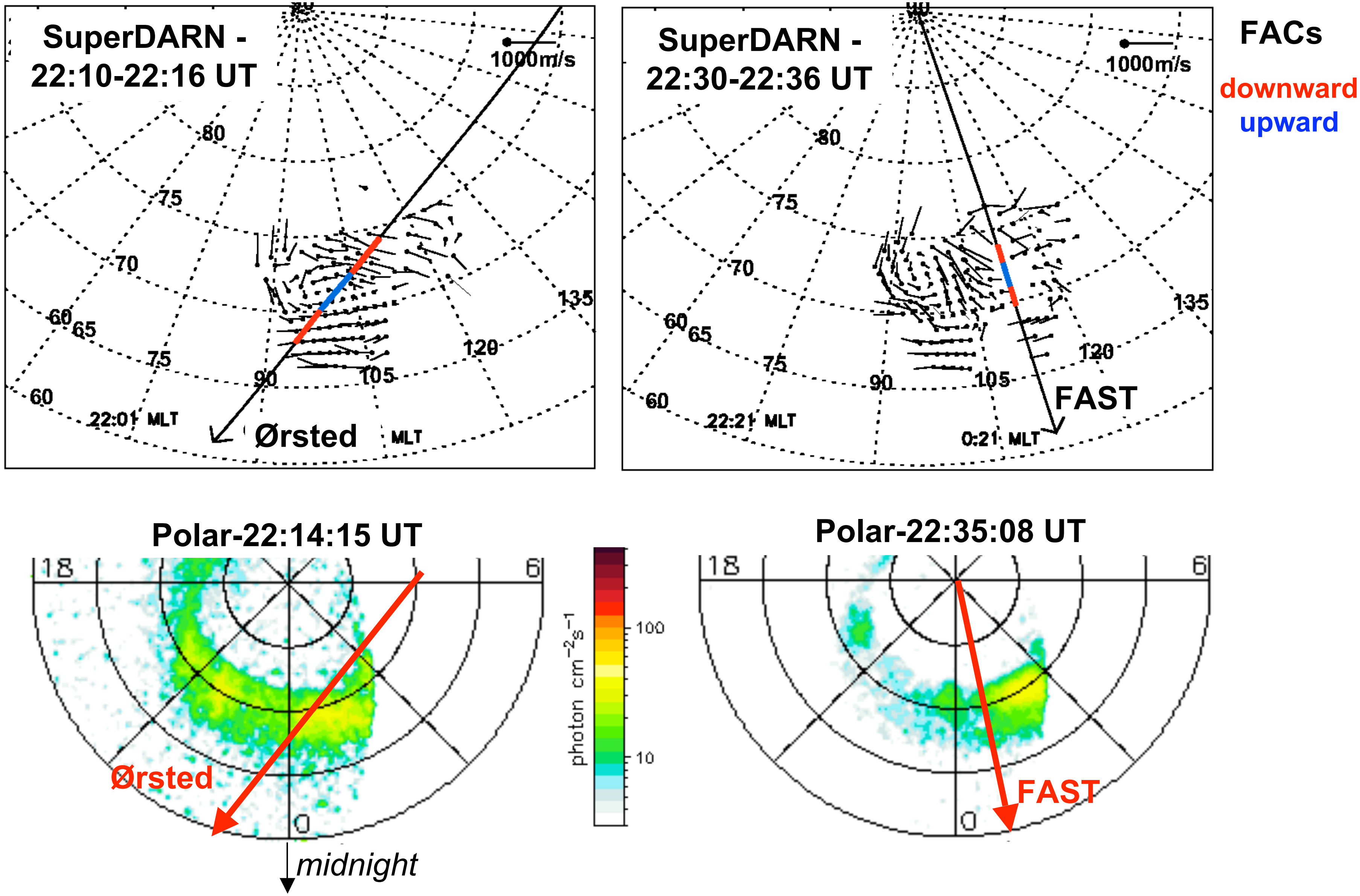
- **Dayside $J_{//}$-Region 1: good monitor of the magnetic storm intensity**
  - initial response of the magnetosphere to the solar wind

Hanuise et al., Ann. Geophys., 2006

Results (2)
Electrodynamics of auroral structures in the dayside and nightside magnetosphere

1. Reconnected flux tube in the dayside (see poster *Cerisier et al.*)
2. Auroral arc in the nightside

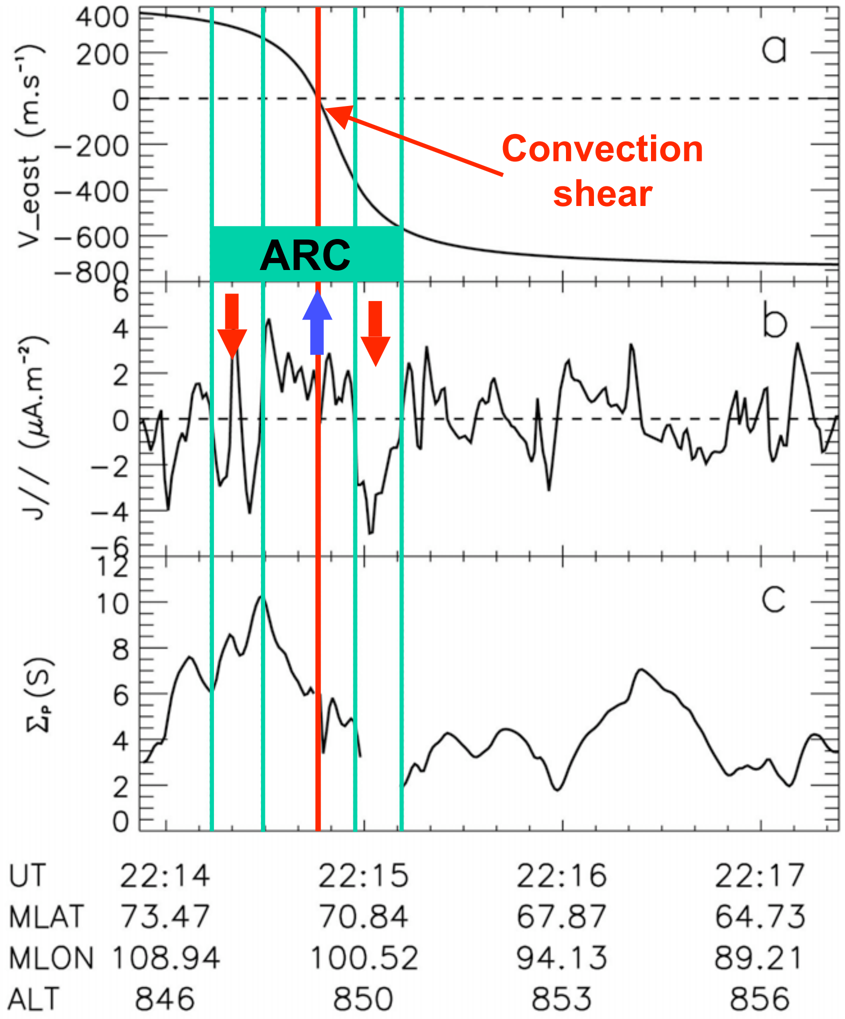
Electrodynamics of an auroral arc – 12/01/2000
convection and precipitation



Electrodynamics of an auroral arc – 12/01/2000

Modelled latitudinal profile of Pedersen conductivity - Ørsted pass

1D modelled Σ_P

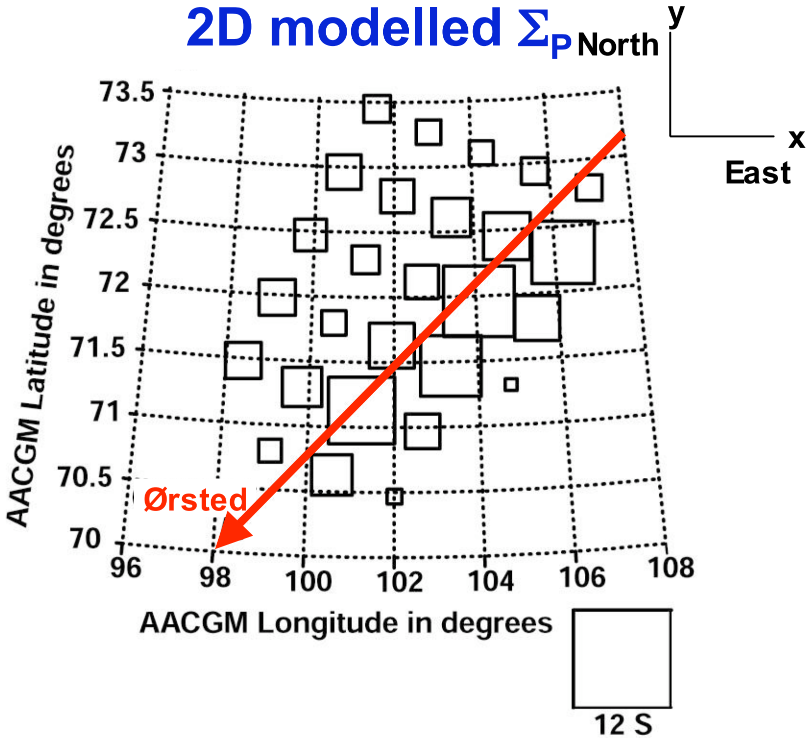


Current continuity

$$J_{//} = -\Sigma_P\left(\nabla_\perp \cdot \mathbf{E}_\perp\right) - \mathbf{E}_\perp \cdot \nabla_\perp \Sigma_P + (\mathbf{b} \times \mathbf{E}_\perp) \cdot \nabla_\perp \Sigma_H$$

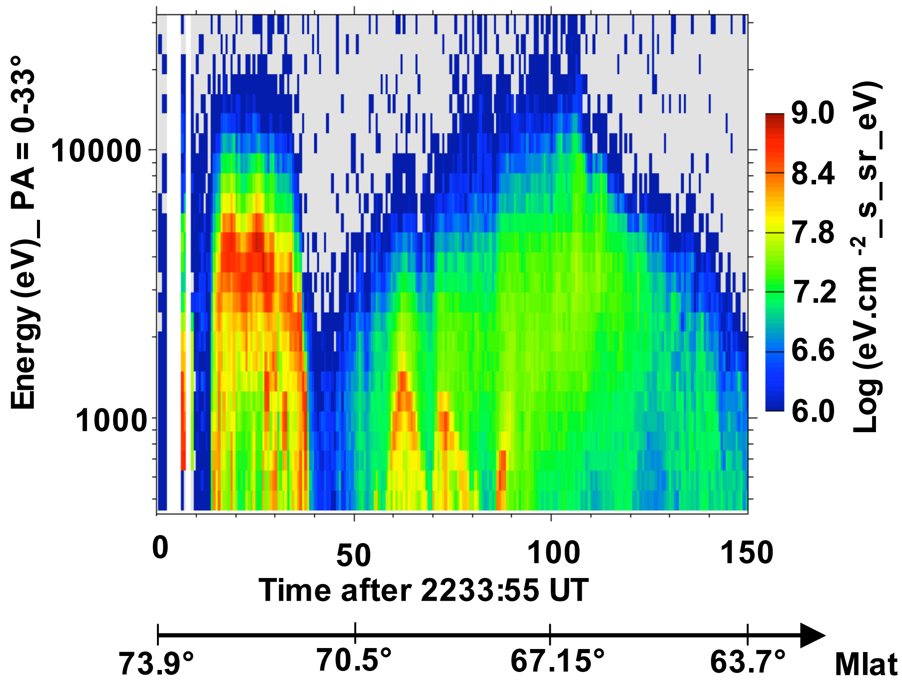
1D : $$\frac{dV_x(y)}{dy} + \frac{1}{\Sigma_P(y)} \frac{d\Sigma_P(y)}{dy}\left[V_x(y) - V_y(y)\right] = \frac{J_{//}}{B\,\Sigma_P(y)}$$

2D modelled Σ_P

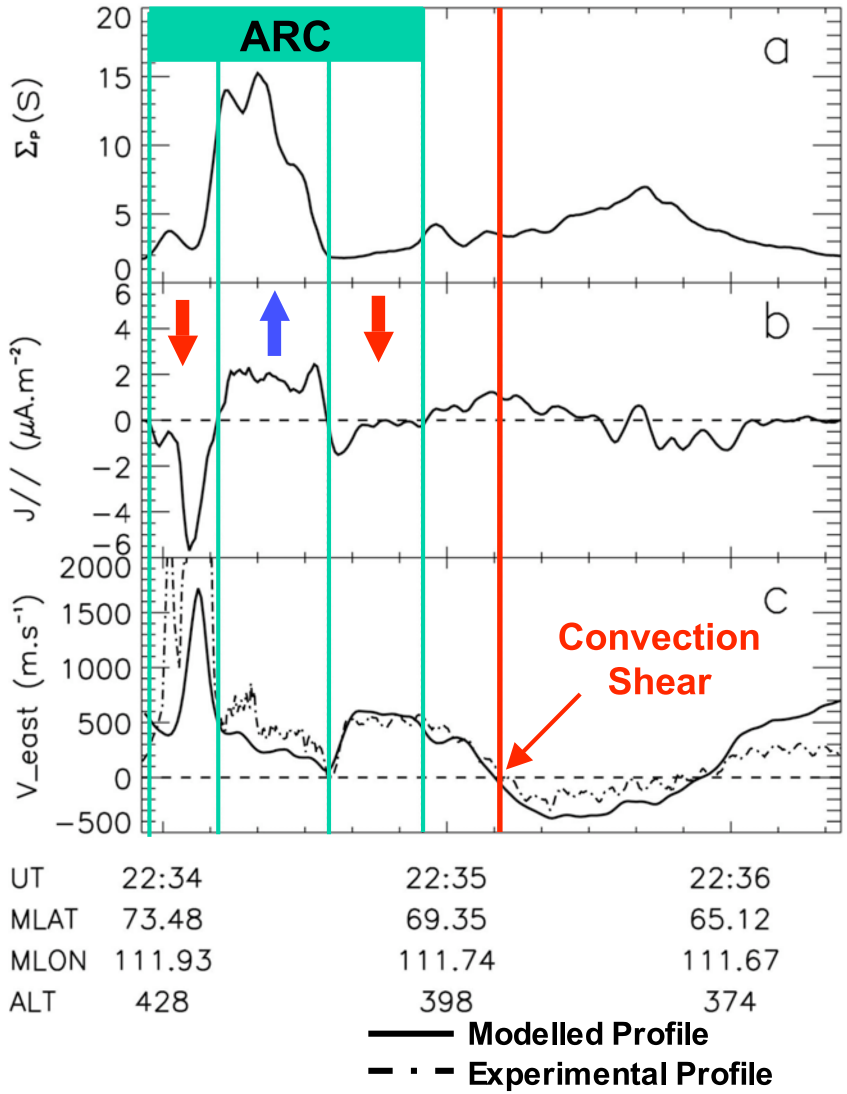


Electrodynamics of an auroral arc – 12/01/2000
Modelled longitudinal profile of convection - FAST pass

FAST Precipitating electrons



1D modelled V_{east}



Current continuity (1D)

$$\frac{dV_x(y)}{dy} + \frac{1}{\Sigma_P(y)} \frac{d\Sigma_P(y)}{dy} \left[V_x(y) - V_y(y) \right] = \frac{J_{//}}{B\Sigma_P(y)}$$

Electrodynamics of an auroral arc – 12/01/2000

Conclusions

- **Full description and model for a meso-scale nightside arc**

  FAST:
  1D structure of the arc → 1D model valid

  Ørsted:
  2D structure of the arc → deficiencies of the 1 D model
  → lack of FACs entries for the 2D model
  SWARM could have solved the problem

- **Electrodynamics**

  - FACs controlled jointly by conductivity and electric field gradients

  - Divergence of the Pedersen currents maintained without convection shear during the FAST pass

Marchaudon et al., Ann. Geophys., 2004

Results (3)
Test of the infinite current sheet hypothesis in the field-aligned currents calculation

(see also poster *Cerisier et al.*)

Test of the field-aligned currents determination for dayside meso-scale structures (cusp injections)

Method: variance analysis of the magnetic signal

Two parameters to discriminate between sheet and tube structures :

1. **Angle a**: direction of the eigenvector associated with the largest eigenvalue of the covariance matrix

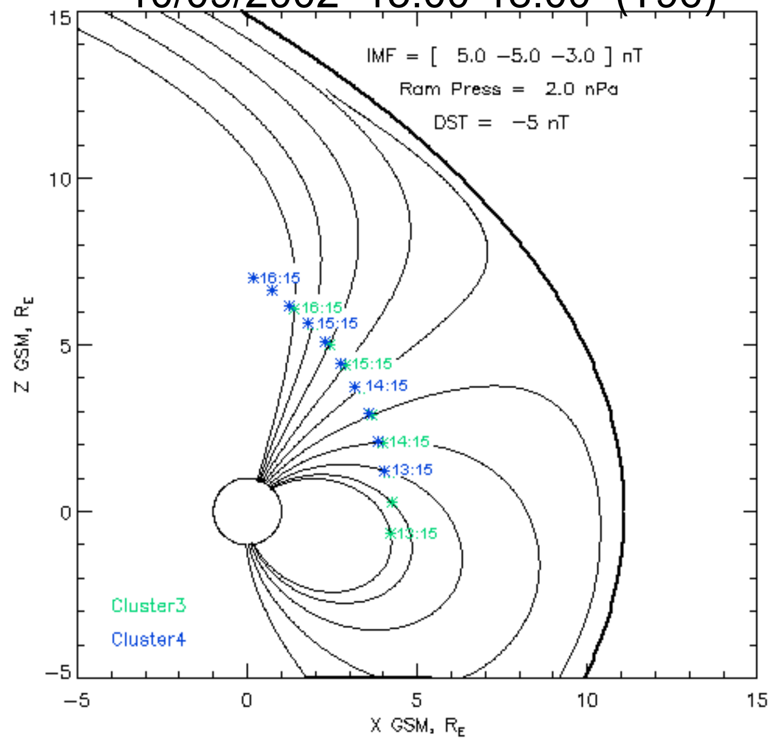
2. **Ratio *r***: between intermediate and largest eigenvalues

Infinite current sheet structure:
***r* = 0 and a = cst**

Current tube structure:
***r* >0 and a oscillating**

Application on Cluster data in the mid-altitude cusp (Cluster perigee)

10/09/2002 15:00-18:00 (T96)

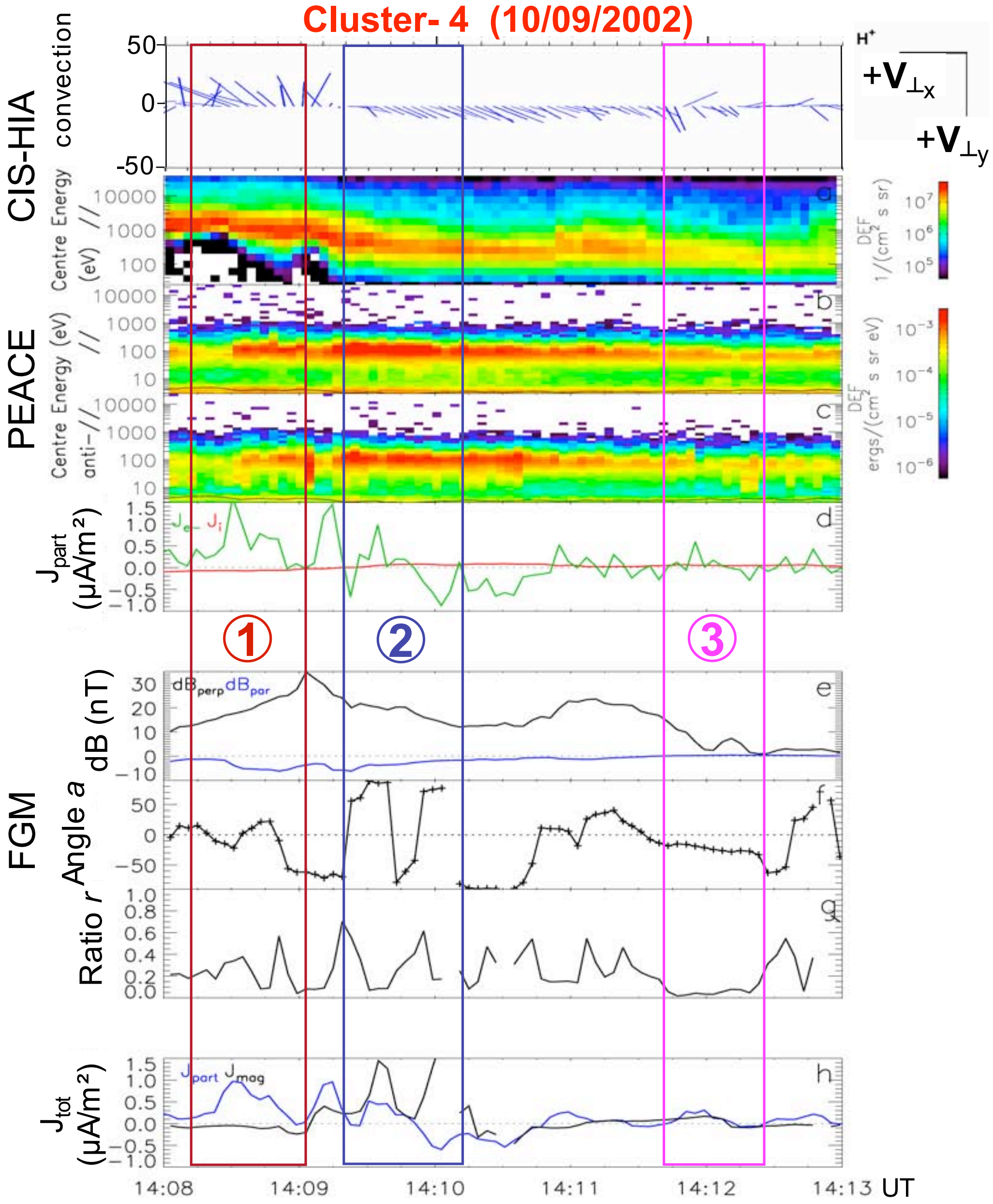


Parallel Currents calculation:

$$\mathbf{J}_{part} = \mathbf{J}_{e-} + \mathbf{J}_{i}$$

$$\mathbf{J}_{mag} = \frac{\vec{\nabla} \times \mathbf{b}}{\mu_0}$$ (single-sc method)

Test of the field-aligned currents determination for dayside meso-scale structures (cusp injections)



1

- Cusp injection sheet-like structure
- Sheet hypothesis valid
- **V_{sh} not zero and rotation**
- J_{part} and J_{mag} not consistent

2

- Cusp injection tube-like structure
- Sheet hypothesis not valid
- J_{part} and J_{mag} not consistent

3

- End of cusp injection sheet-like structure
- Sheet hypothesis valid
- J_{part} and J_{mag} consistent

Marchaudon et al., to be submitted, 2006

Conclusions

Science point of view

• Region-1 of field-aligned currents is a **good monitor** (extremely sensitive) of the solar wind activity

• Meso-scale auroral structures generate a **large part of the convection and of the currents** existing in the magnetosphere-ionosphere system

• **Tube-like current structures** of the injections in the cusp region

Instrumentation point of view

• **Properties of field-aligned currents at different altitudes** with magnetic conjunctions between low- and high-altitude satellites (Ørsted, Cluster)

• **Field-aligned currents pattern with respect to IMF directions** with magnetic conjunctions between several low-altitude satellites (Champ, Ørsted)

• Need **plasma data** in the magnetosphere and/or in the ionosphere to complete the electrodynamics picture

Perspectives with the SWARM Mission

• **Curlometer technique applied to field-aligned currents with SWARM A and B:**

2D reconstruction of the auroral electrodynamics

- 2D field-aligned currents with SWARM
- 2D electric field pattern with SuperDARN

• **Symmetry and asymmetry of the field-aligned currents pattern with SWARM A, B and C:**

- dayside/nightside pattern
- dawnside/duskside pattern with respect to IMF conditions