Science & Technology Facilities Council

Opportunities for the SWARM mission: the effect of the ring current

M W Dunlop, Q. -H. Zhang[2], H. Luhr[3], I. Dandouras[4], C. Shen[5], J. Eastwood[9], R. Holme[6], J. Cao[7], Y. Bogdanova[8], M. Lockwood[1], Y. Kamide[2], W. Baumjohann.

Ring Current analysis:

Cluster direct sampling of the RC

Impact for signals at SWARM (LEO)

Influence on the ground dB/dt

SWARM planning:

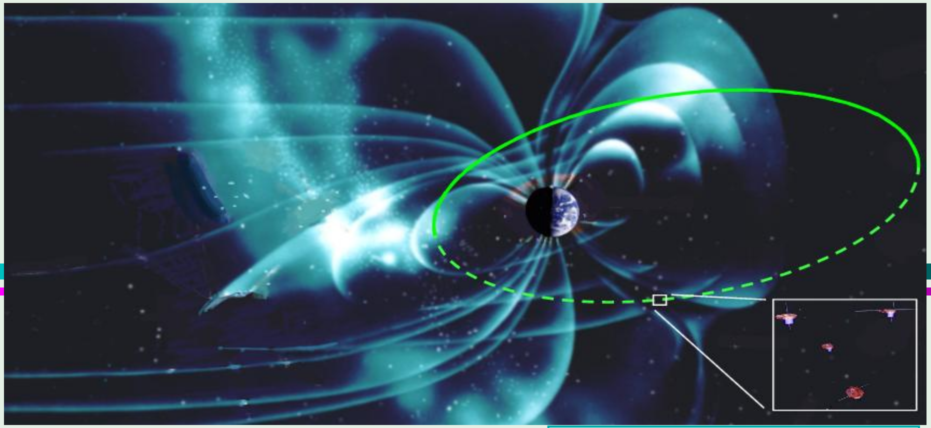
Cluster-SWARM coordination

Use of other data sets: RBSP, …

esa

Cluster experience:

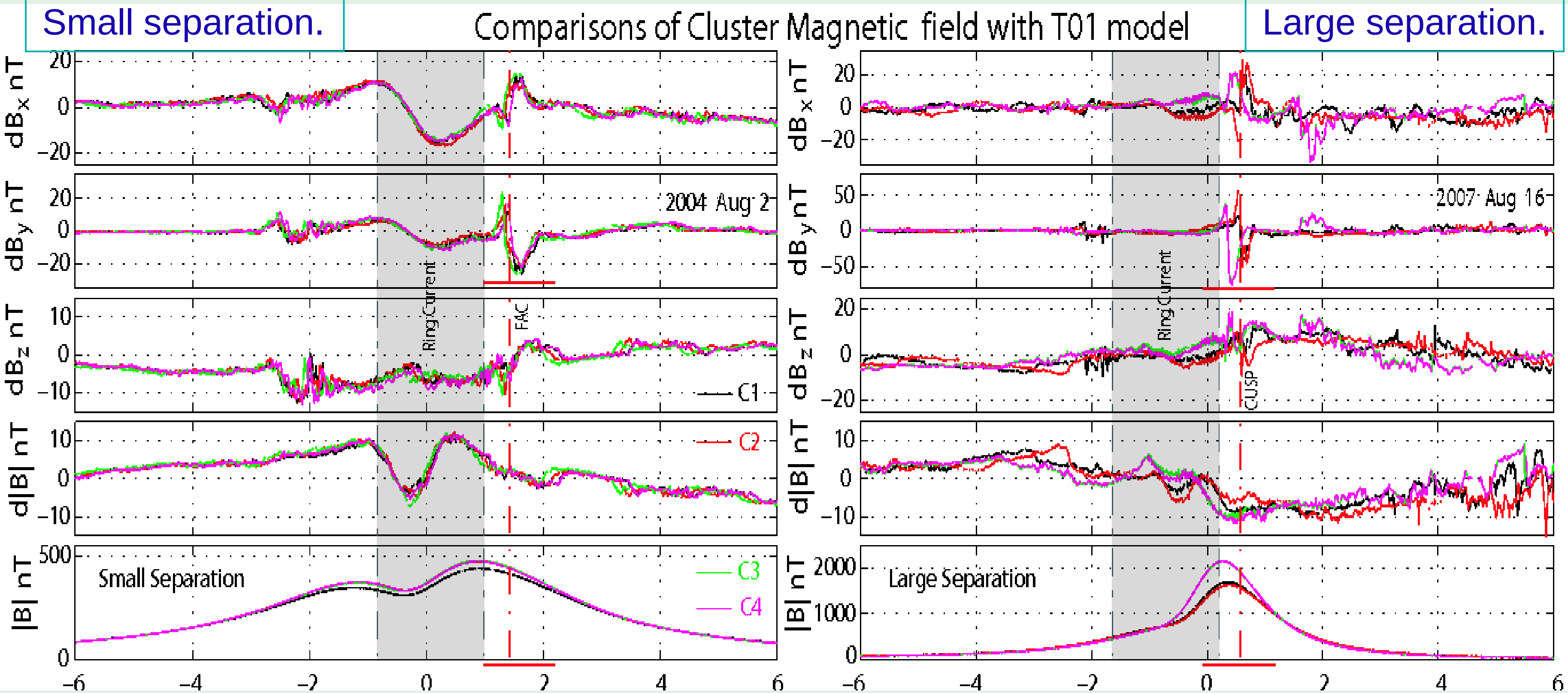
The four Cluster spacecraft, sample the ring current, near Earth cusp and region 2 field aligned currents (FACs) around perigee.



The separations of the spacecraft vary from a few hundred to several thousand km.

Small separation.

Large separation.



Results from two orbits with different separation distances; x-axis is time relative to perigee.

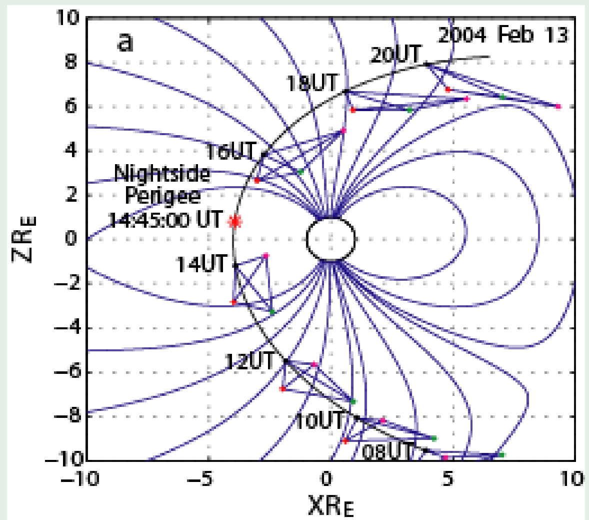
Cluster four spacecraft configurations:

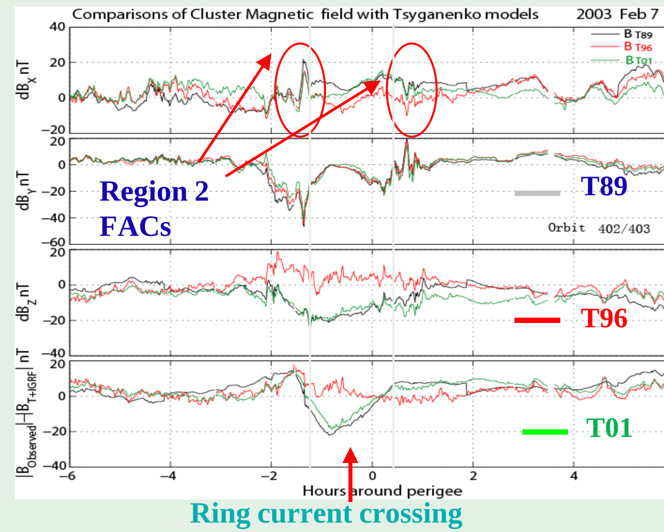
Orbit evolution produces changing constellations through each region

Use of different models subtracted from the data can highlight particular features

Orbit plots in the GSM XZ plane for night-side and dayside orientations:

highly distorted configurations can occur.



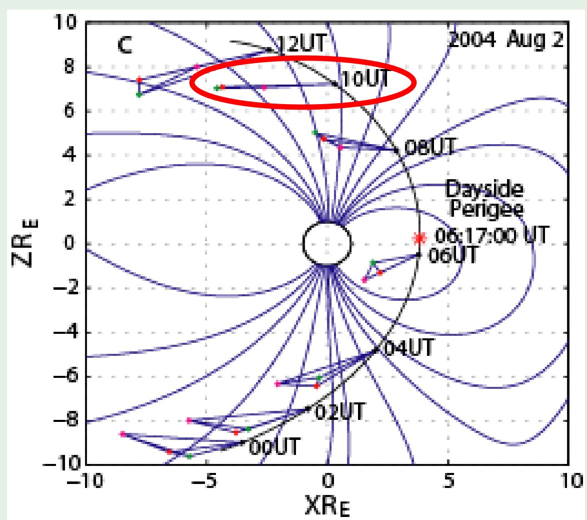


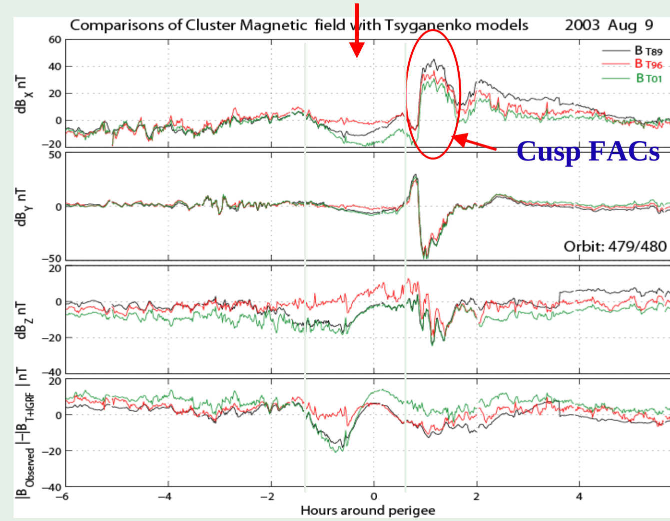
Magnetic field residuals from comparison of Cluster 1 observations:

Choice of Tsyganenko model

Choice of input conditions

night-side and dayside passes show FACs from both cusp and region 2.

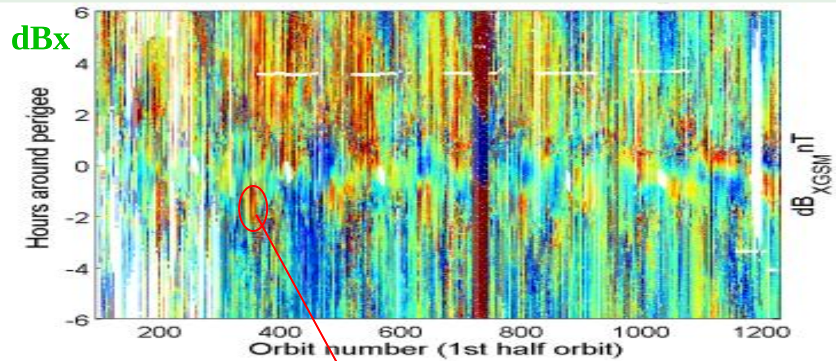


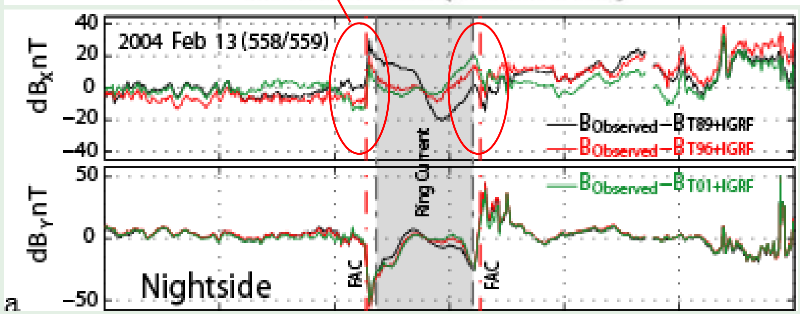


First survey of ring current and FAC system: Cluster perigee passes

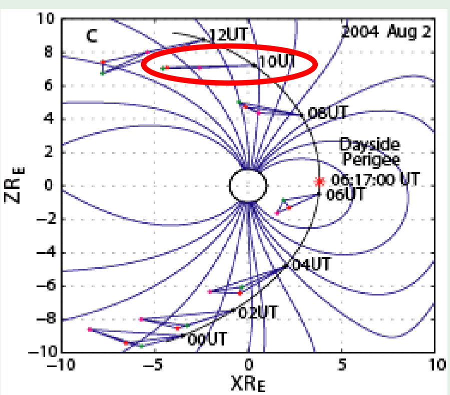
[*Zhang and Dunlop, 2011; Dunlop and Balogh, Ann. Geo. 2005; Shen and Dunlop,* **SR-008**, *2008*]

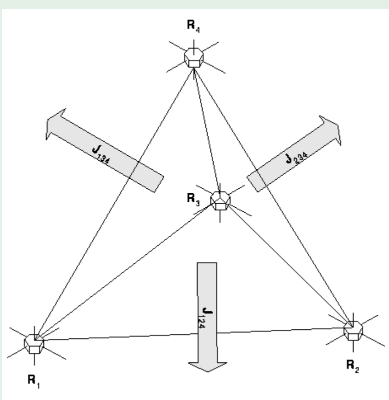
- Unique database from 10 years of Cluster operations; wide range of solar activity.
- Better understanding of external currents is vital to improve models of the Earth's internal environment.
- Stronger ring current affects Earth's dipole and field strength inside ring current (LEO coordination).





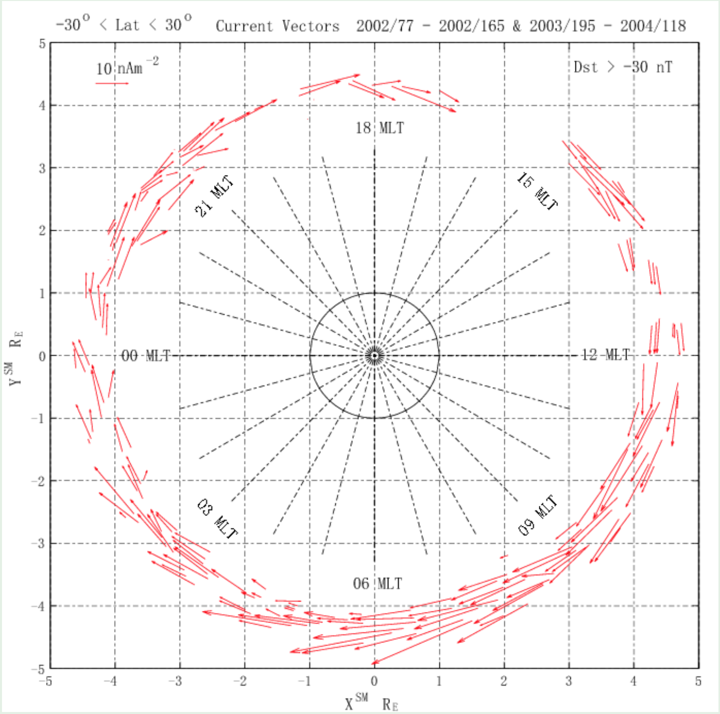
- Comparison to magnetic field models also identify the highly dynamic external currents
- Provides *first*, full azimuth scan of the Earth's westward flowing ring current (**Hazardous region for GPS and communication**).
- Shows dawn-dusk asymmetry, fed by field aligned currents into ionosphere (**influences internal magnetic field**)
- Cluster tools have been adapted: **will assist preparation for SWARM mission**





Estimate of electric current:

Adaptation for azimuthal (J_φ) and field parallel ($J_{||}$) components

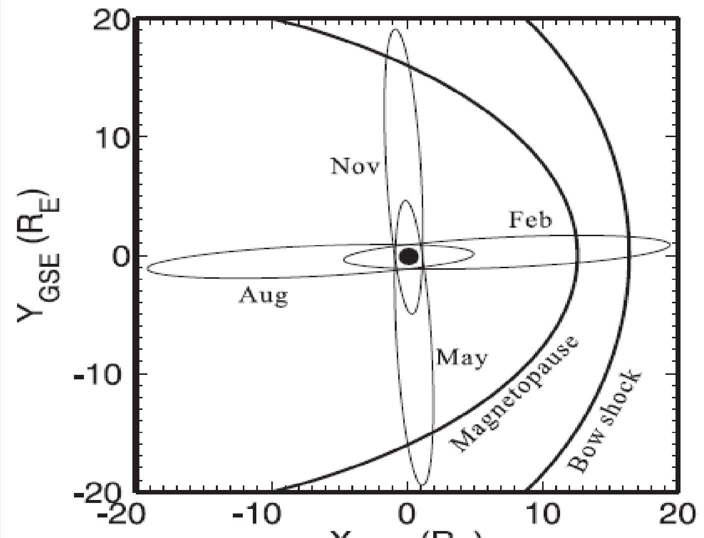


Distribution of the ring current:

Toroidal-shaped, equatorial, westward current distribution (radial range: ~2-7 Re).

Gradient drift of trapped energetic particles [Singer et al., 1957; Le et al. 2004].

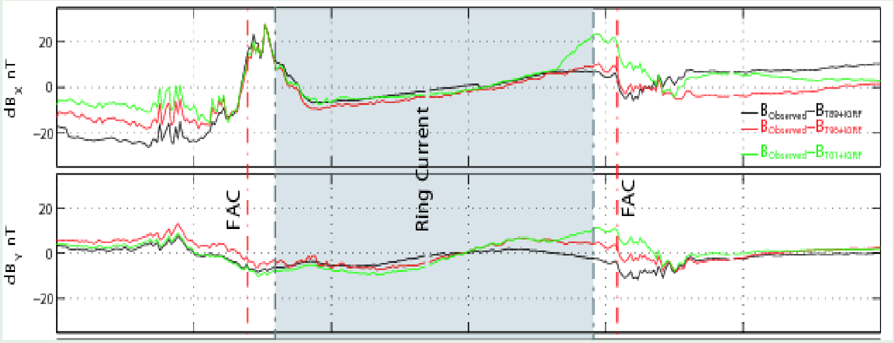
Cluster has often crossed the RC during its 11 years of operations.

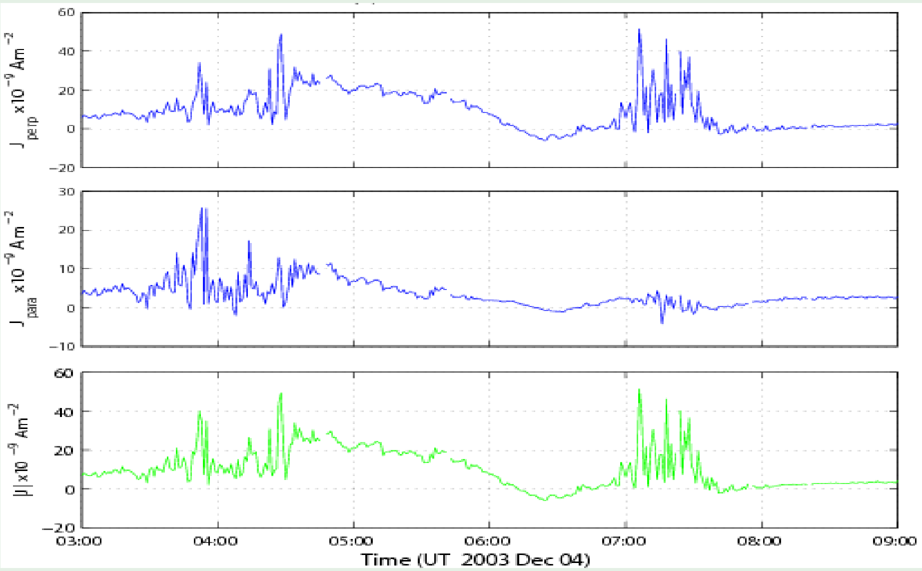


Escoubet et al., 2001

Curlometer: point by point calculation

(divB , s/c configuration and temporal stability).





Direct curl B calculations can identify the FAC structure and Ring Current :

- Filamentary small scale signatures: some are FAC, but not all, and temporal behaviour is often present.
- Ring current is generally well defined, but requires particular constellations for high accuracy.

Could test SWARM FAC ‘curlB’ method using pairs of Cluster spacecraft and comparison to the full curlometer (4 s/c).

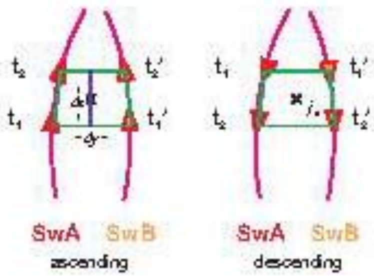
Swarm Mission Concept Calculation of FAC

Calculation of Field-Aligned Currents (FACs)

The basic equation for determining the electric current density j from magnetic field observations B is Ampere's law. If two satellites are moving side-by-side, the FACs may be computed from the spatial gradients of the horizontal magnetic field [1], [2]:

$$\mathrm{curl}\,\mathbf{B} = \mu_0\,\mathbf{j} \qquad j_z = \frac{1}{\mu_0}\left(\frac{dBy}{dx} - \frac{dBx}{dy}\right)$$

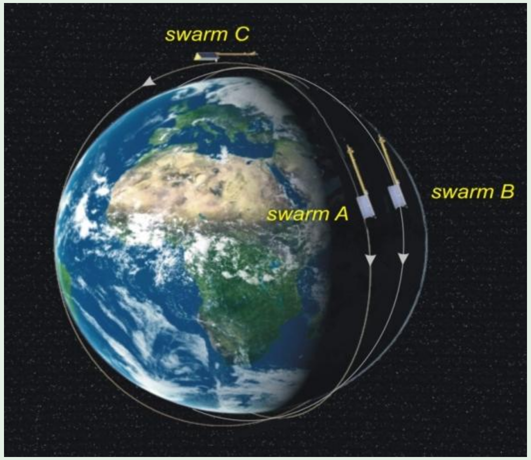
To use this equation on measured data, the following configurations are employed:



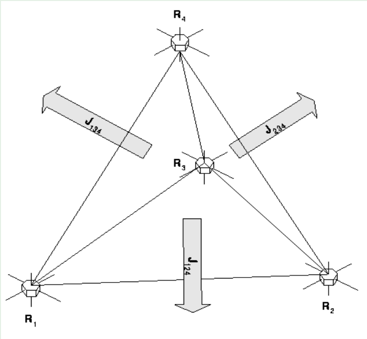
Ritter et al.

The field differences in x-direction are obtained from measurements taken from each satellite (**SwA** and **SwB**) at subsequent positions (Δt=5sec). The differences in y-direction, however, are taken at orbit-simultaneous positions of the two satellites. As there are 4 measurement points available for the gradients the mean value of each difference pair goes into the above equation:

$$j_z = \frac{1}{\mu_0}\left(\frac{dBy_A + dBy_B}{dx_A + dx_B} - \frac{dBx_{t_1} + dBx_{t_2}}{dy_{t_1} + dy_{t_2}}\right)$$



Lessons Learned From Cluster !!



One face:

$$(\nabla \times B)\cdot(r_{12} \times r_{13}) = \Delta B_{12}\cdot r_{13} - \Delta B_{13}\cdot r_{12}$$

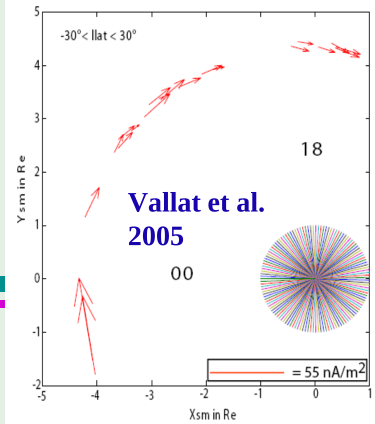
Comparisons between 4-spacecraft:

- Current components through each face: spacecraft configuration and scale are important.
- Local extent of FACs can be investigated in some detail using combination of boundary and curlometer analysis.
- Best estimates of particular components of curl B (Jϕ and J||) depend on sampling (orientation to RC).

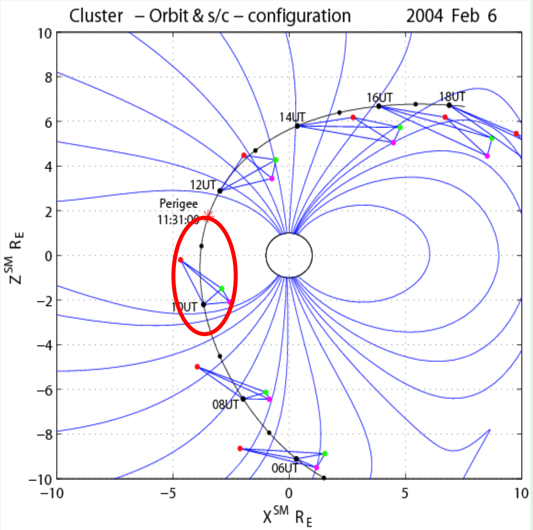
Distribution of the ring current:

Direct measurement of the Earth's (non-storm) ring current.

Extends previous study of partial ring.

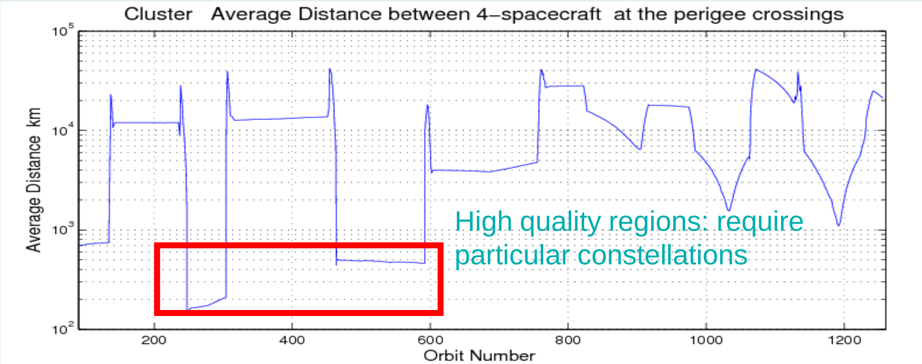


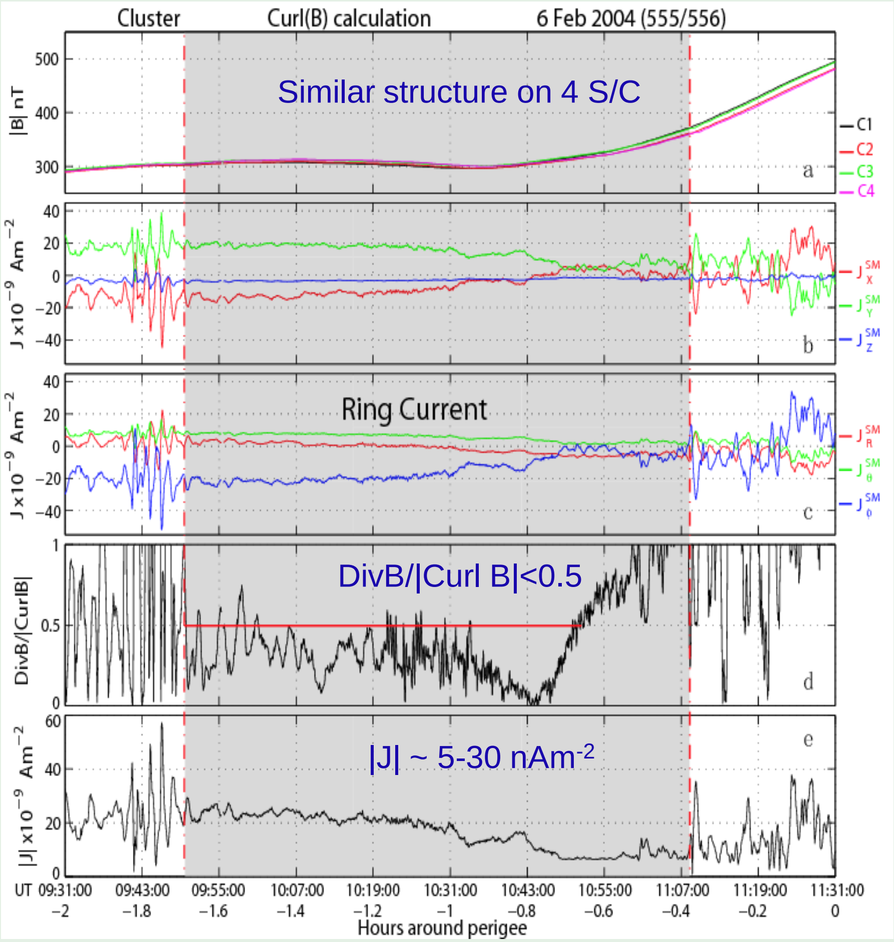
Single pass: Cluster moved from the pre-midnight sector (21 MLT) south of the magnetic equator through perigee at 11:31 UT (1.6 MLT) to the pre-midnight sector (13.8 MLT) north of the equator.



Jz &Jr ~0 : **J** equatorial

J_φ<0 : westward





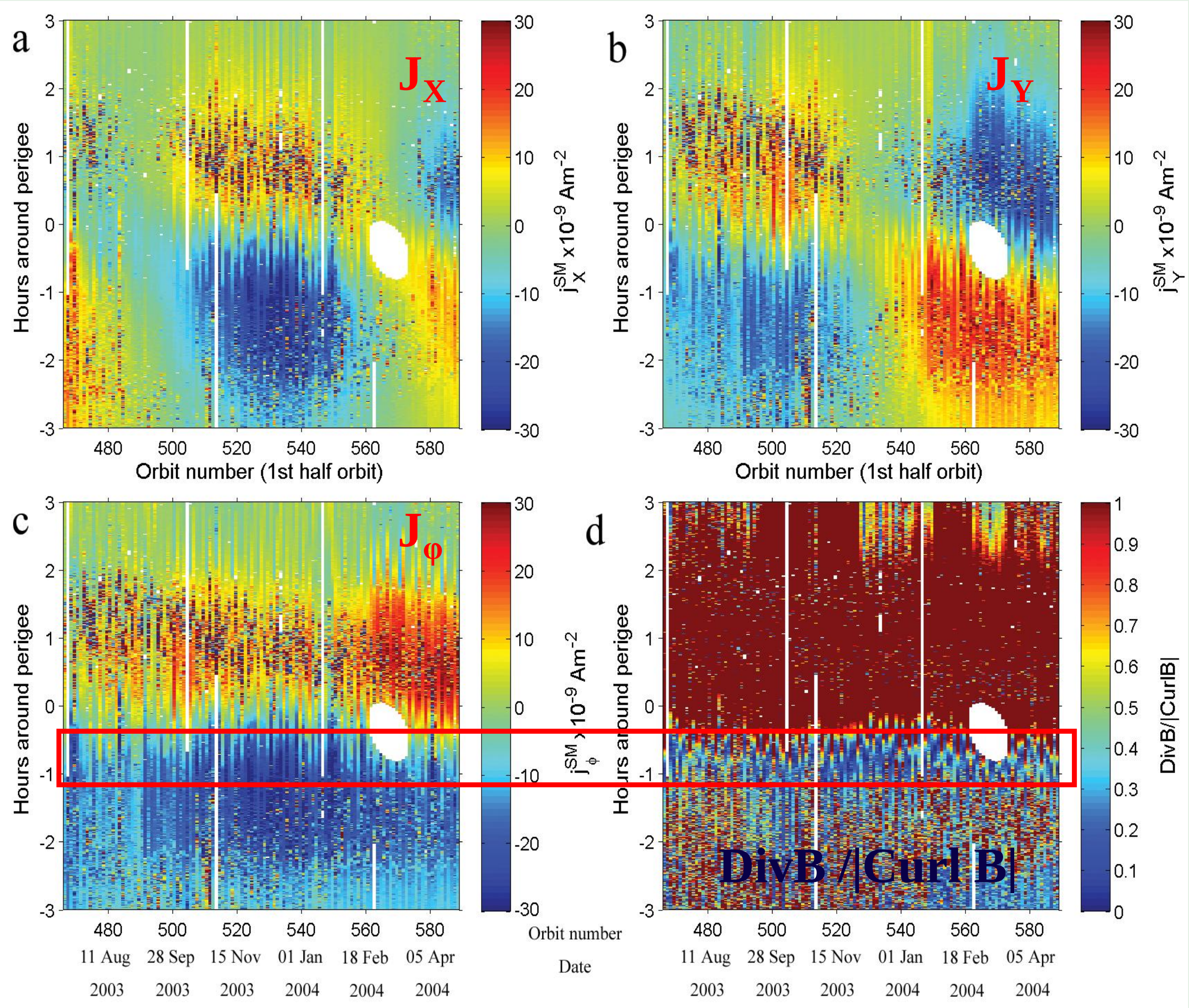
Distribution of the ring current:

Results from one year pass

- J_X & J_Y varied with MLT

- J_φ<0 clockwise current

- DivB/|Curl B|<0.5
  results generally reliable



Ring current analysis: first, full azimuth scan of westward flowing RC

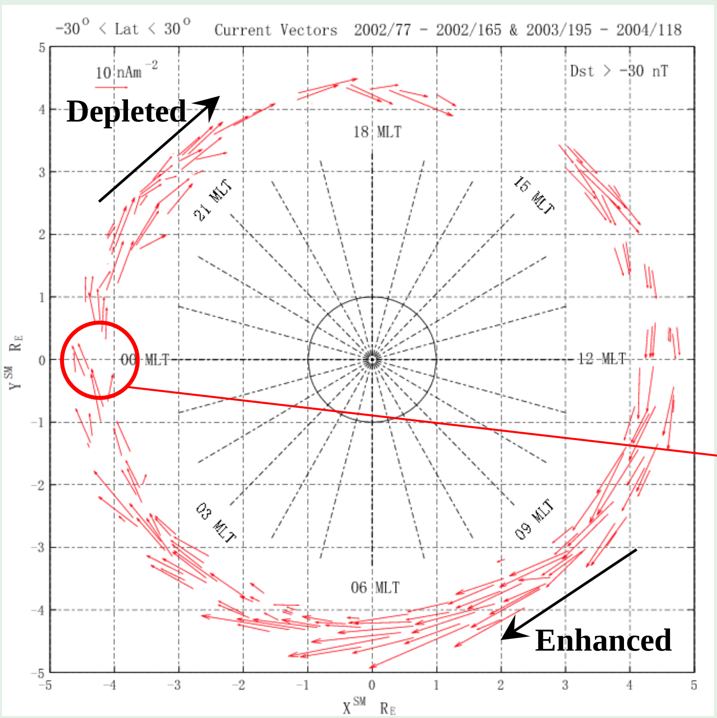
- The Cluster array often samples a well defined RC plasma signature during each perigee pass
- Adaptation of curlometer for azimuth (J_φ) and parallel ($J_{||}$) components.
- New field curvature and rotation analysis may provide enhanced results [*Shen et al. 2012*]

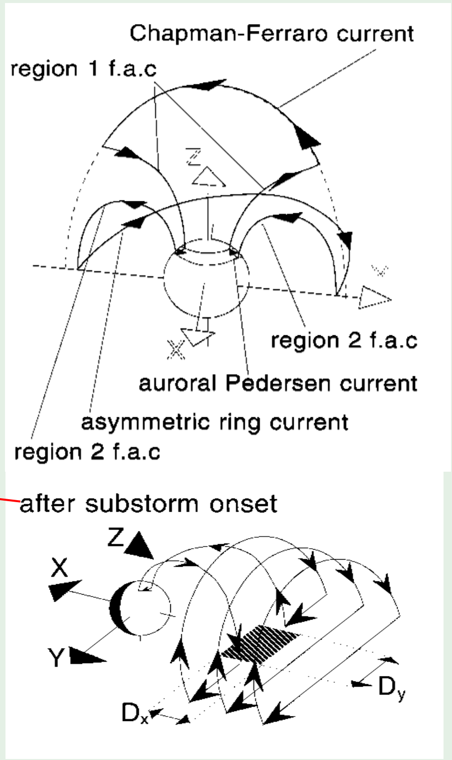
• RC grows away from noon on dawn side (fed by upward R2 FACs)

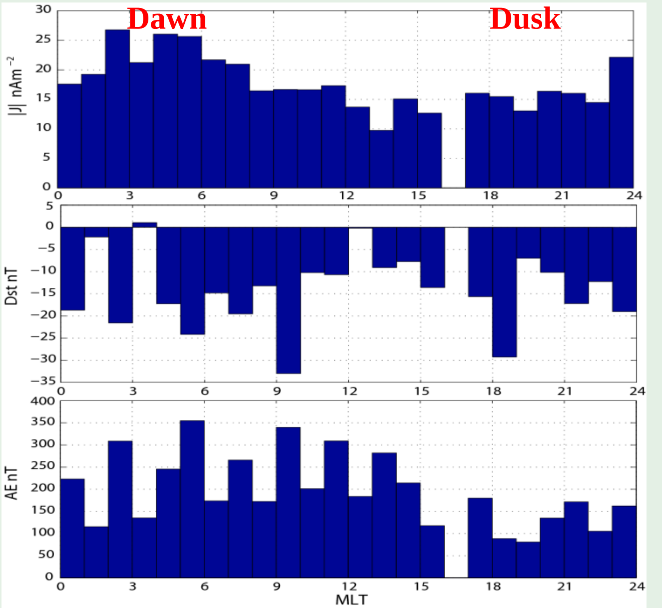
• RC decays on duskside towards noon (feeds downward R2 FACs)

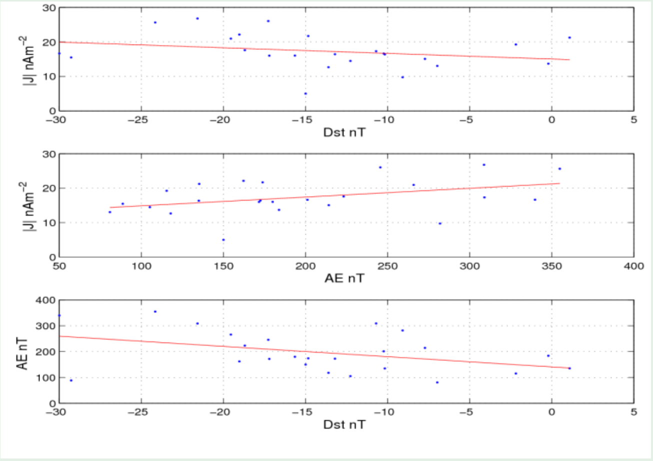
• Minimum near midnight: possible inner edge SCW DP1current [*McPherron, 1973*]

• Correlations with AE and Dst show that seasonal and dynamic variations do not account for the dawn-dusk asymmetry.









Comparison to LEO measurements:

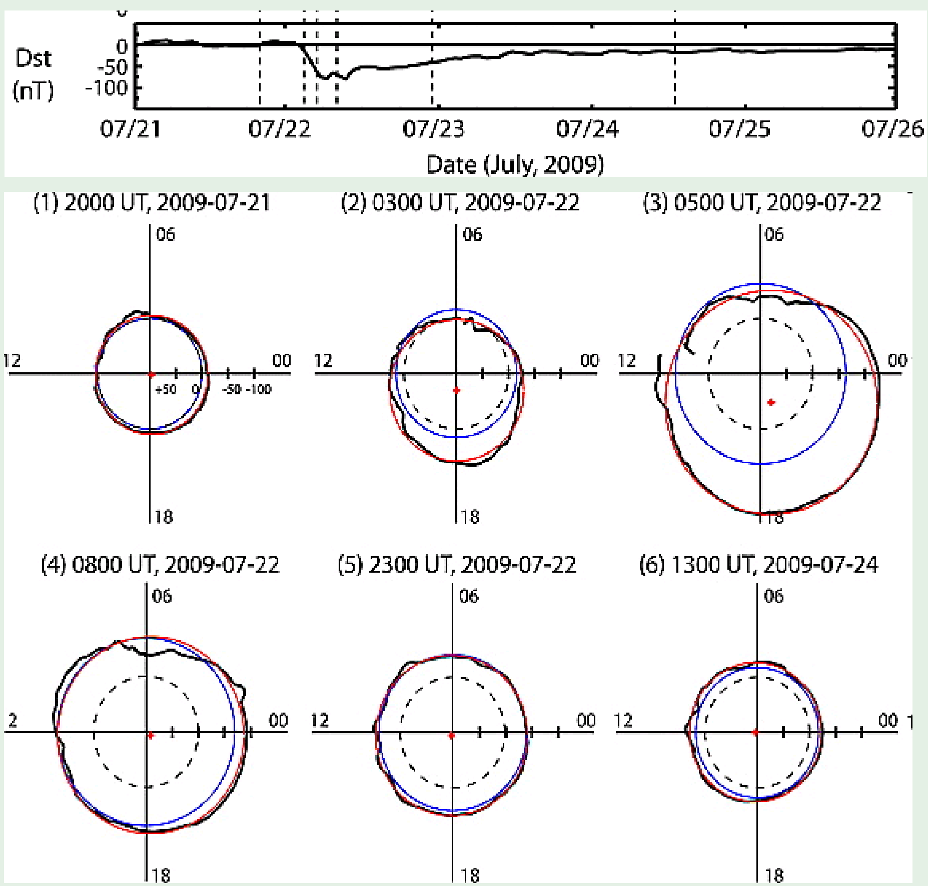
Low-Earth, equatorial satellite C/NOFS shows a local time dependence of the ring current field during quiet and disturbed conditions (strong, dusk-side enhancement).

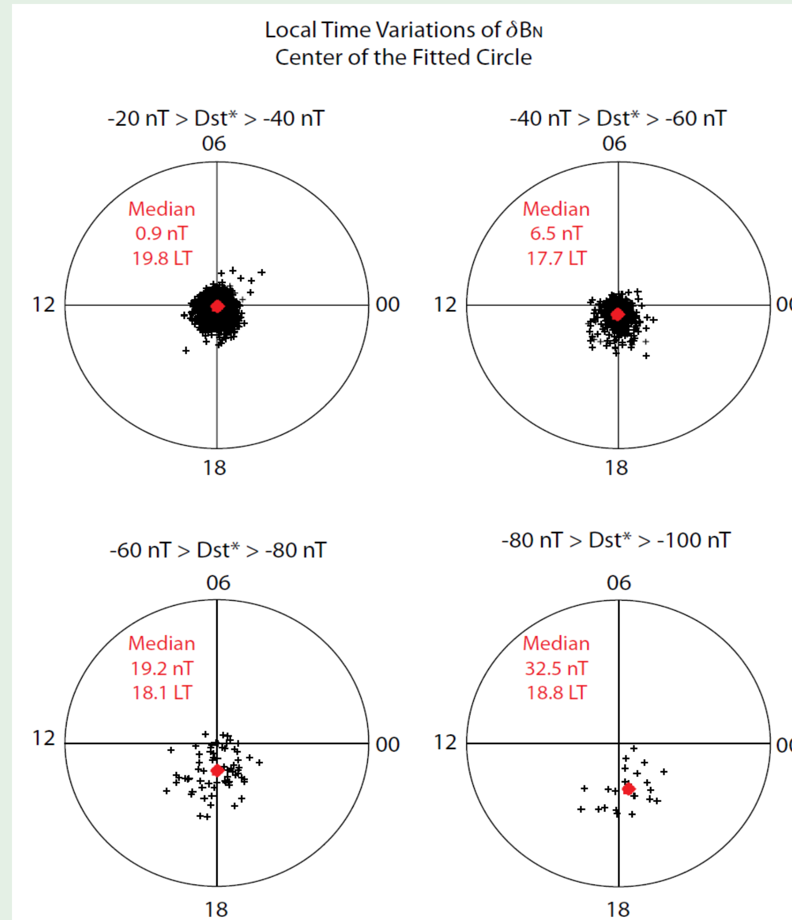
Fitted data (left) are during a typical storm sequence

Plots are the locus of each residual δBn around LT, centred on the fitted dashed circles (δBn=0).

Red circle and centre points fit the blue data trace; centre points are shown statistically on the right.

Blue circles represent the prevailing Dst for each UT.





A coordinated multi-point investigation of electric currents flowing in the magnetosphere and ionosphere

SSVO proposal (accepted): PI Jonathan Eastwood (**jonathan.eastwood@imperial.ac.uk**)
Imperial College London

- **The SWARM magnetic field measurements will include a significant 'magnetospheric' component.**

- This magnetospheric component is highly structured and highly dynamic, with processes operating on time-scales from less than a minute to essentially quasi-static behaviour.

- We will examine the impact of **two particular 'contaminants'**:
  - » Storm-time magnetospheric current systems.
  - » Transient current systems due to e.g. Hot Flow Anomalies which create dramatic pressure pulses and subsequent magnetopause motion.

- Approach:
  - » Catalogue when SWARM data is affected by these phenomena; characterise the impact.
  - » Study SWARM magnetic field data in the context of in situ magnetospheric measurements from **Cluster**, **THEMIS** and **ARTEMIS**.
  - » Use remote + in situ measurements from the **CINEMA** and **TRIO** CubeSats.

Conclusions:

1.Unique database from 10 years of Cluster operations, covering a wide range of solar activity:

allows detailed comparisons to test observed behaviour and gain better understanding of external currents to improve models of the Earth's internal environment.

2. Provides *first*, full azimuth scan of the Earth's westward flowing ring current:

dawn-dusk asymmetry; possible fed by region 2 field aligned currents into ionosphere

changes in RC influence internal magnetic field.

3.The adaption of Cluster tools (Curlometer) will assist preparation for Swarm data interpretation with < 4 spacecraft.

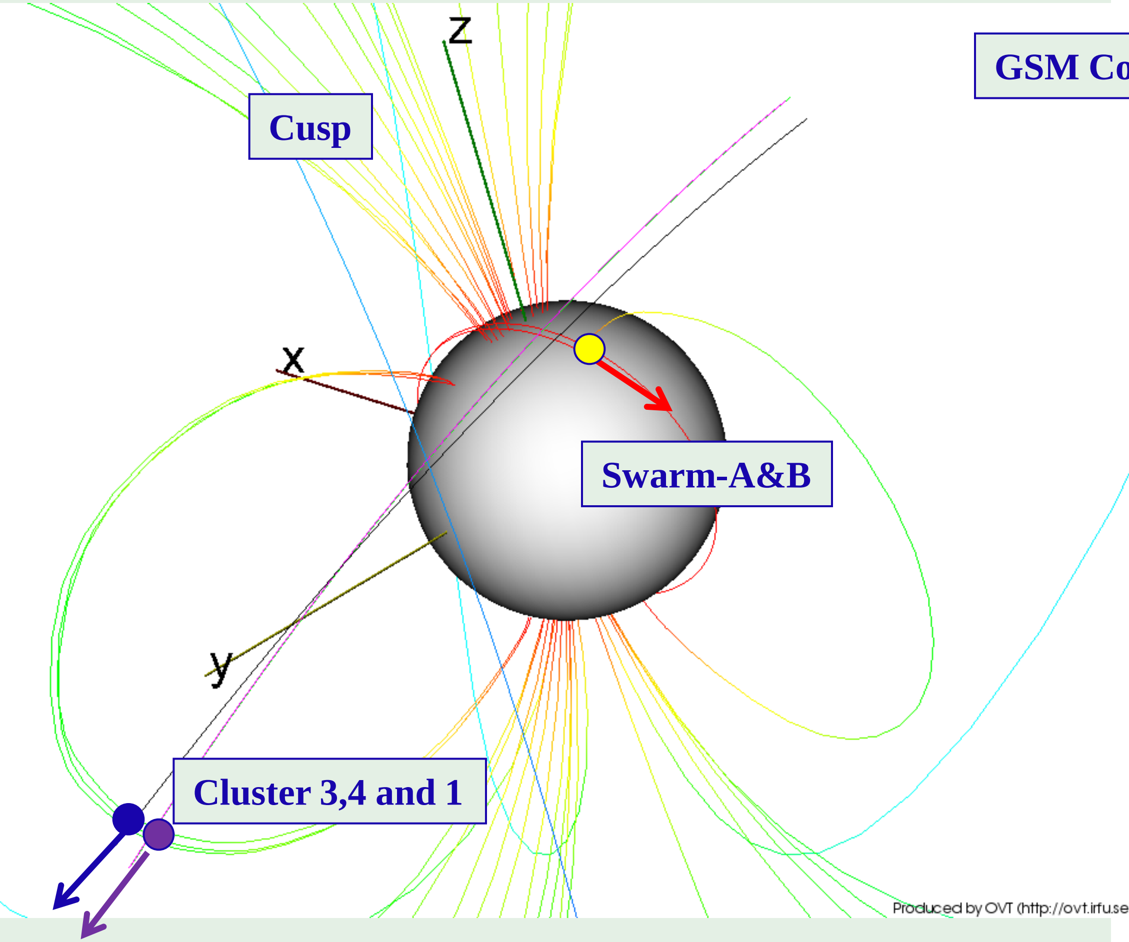
4. Comparison to existing LEO equatorial data shows a discrepancy between the *in-situ* RC and near Earth signals.

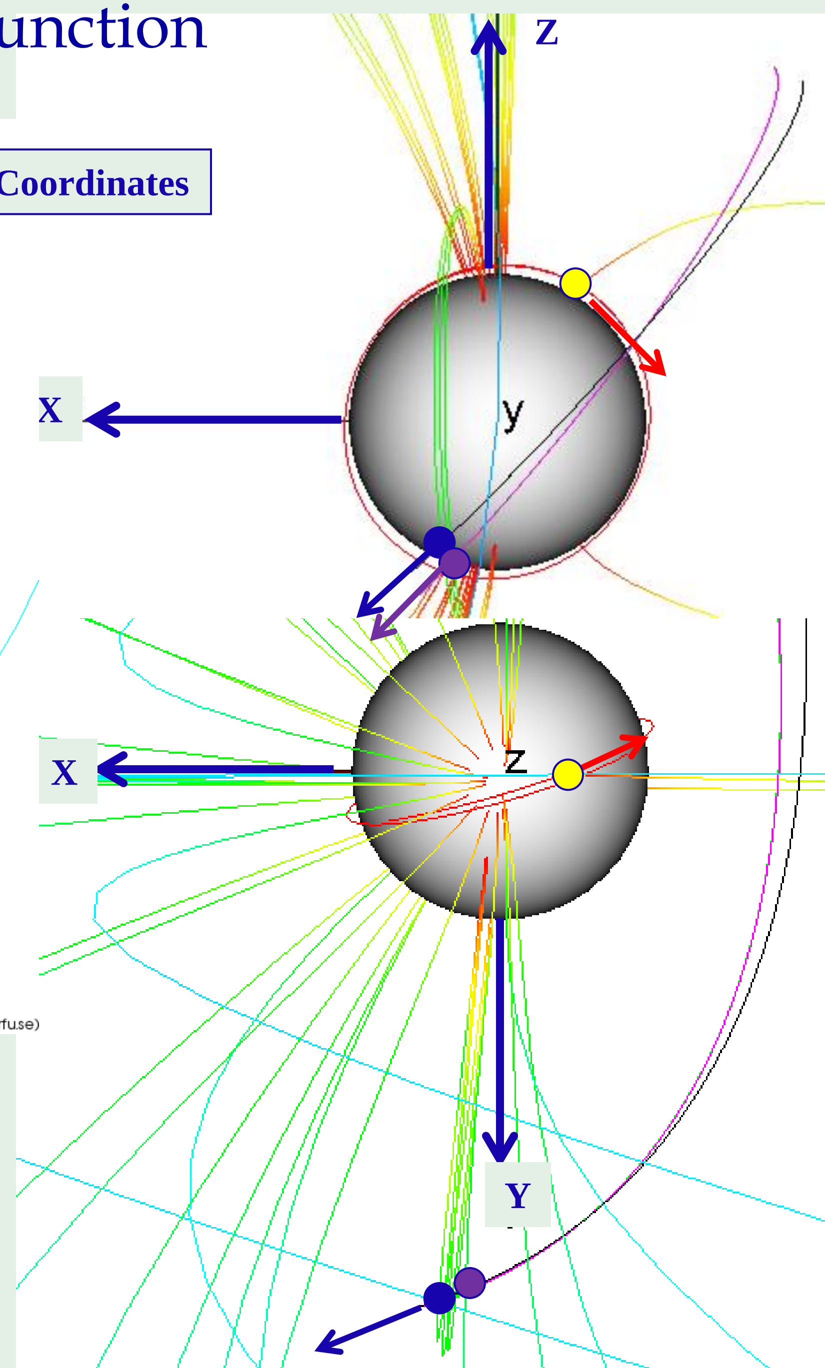
5. Connection through R2 FAC is a possible cause but further work is needed:

seek clarification with the Swarm polar coverage

Opportunities for direct coordination with Cluster (see Fazakerley et al. poster).

Swarm-Cluster conjunction





Ring Current Region (~55° ilat footprint; L ~ 3)
Swarm-A&B sample ring current FAC at ~00:00 MLT
Cluster 3,4 and 1 sample RC FAC but at ~17:00 MLT
These are simultaneous, at 2013-04-24 09:58 UT

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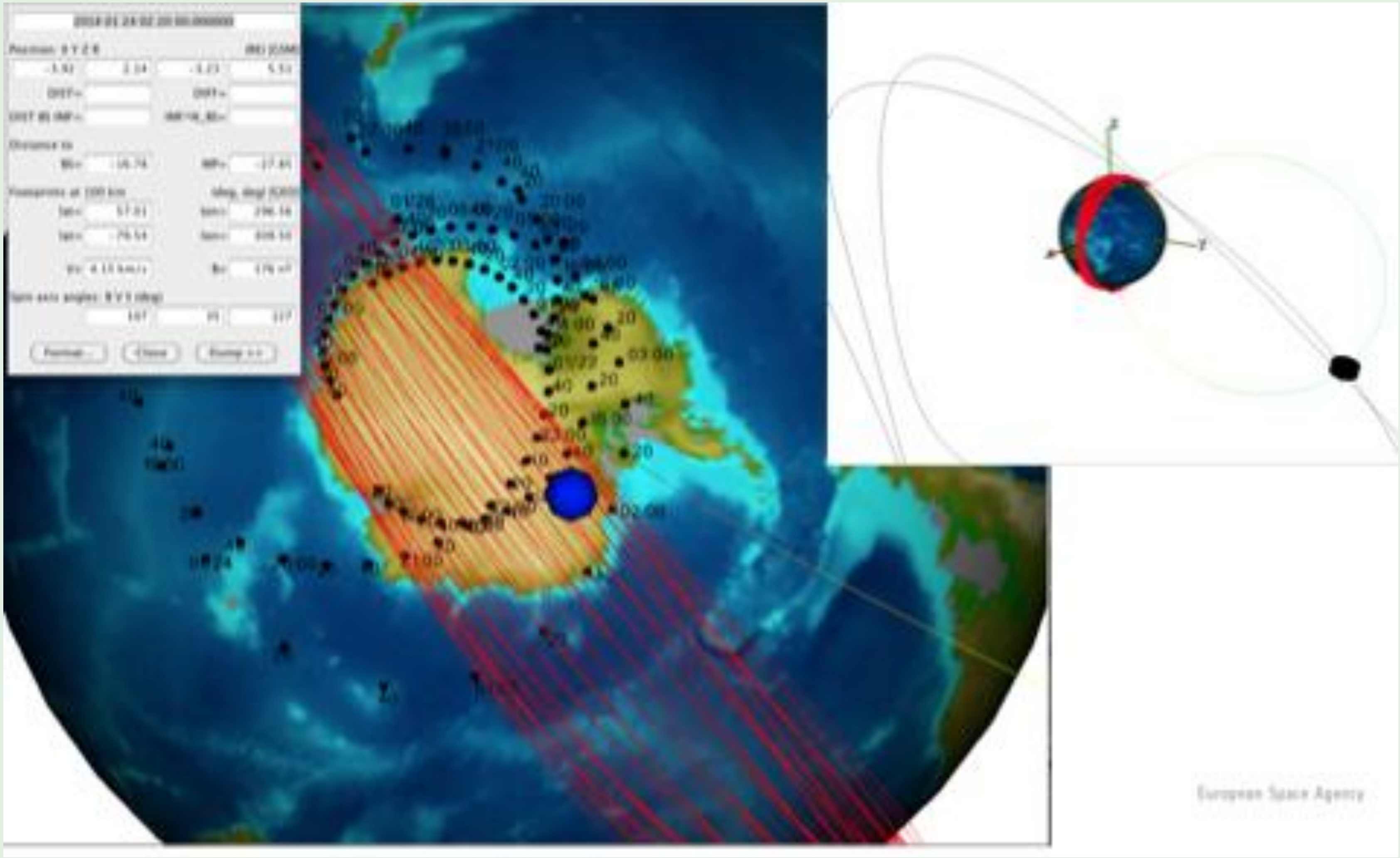


SWARM Electric field verification:

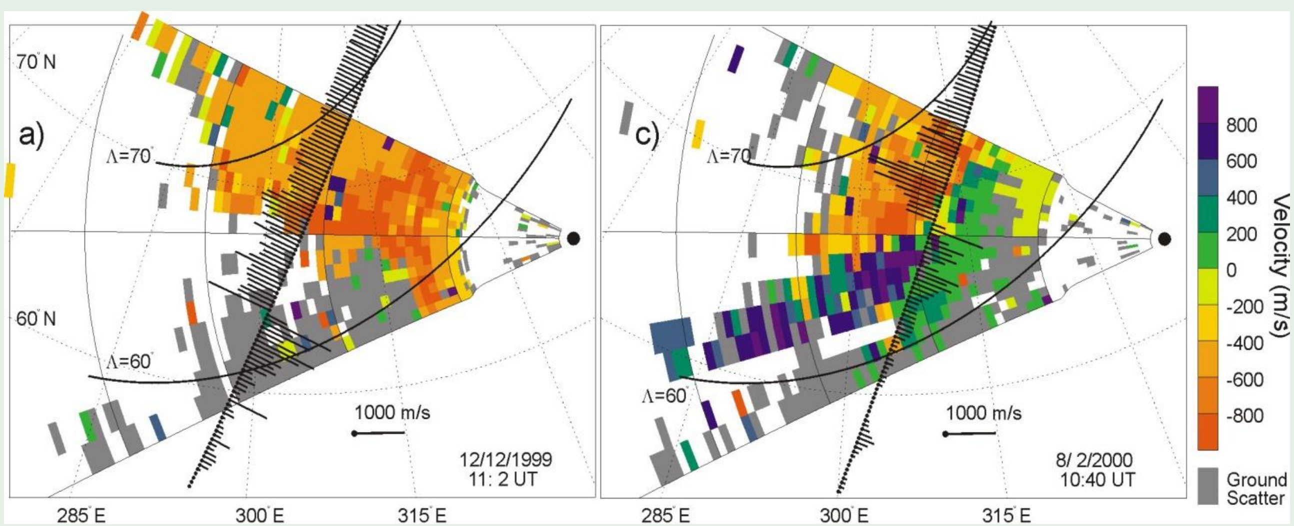
Below, an example of the use of incoherent scatter radar data to evaluate the effective electric field measured at low atitude (actually using SuperDARN velocity), taken from *Drayton et al.* [2005], is given.

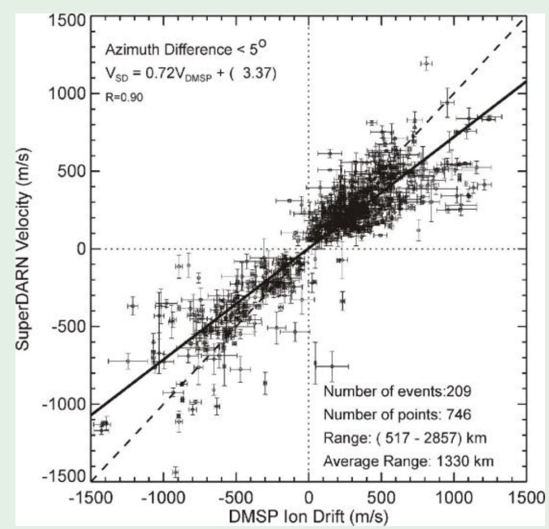
The messages taken from this are:

1) Although there are many passes which are suitable for comparison, the passes selected have to be carefully chosen from a geometrical point of view. Also, to make the comparison inaccurate, stable flows are desirable.

2) Individual passes have a lot of scatter, so comparisons have to be done statistically. The velocities measured by SuperDARN are about 20-30% less than those measured by the satellites.

Recent work between between DMSP and SuperDARN suggests this comparison can be improved and SWARM is designed to allow routine opportunities for such conjunctions.





Cluster separation strategy