Geospace I: Ionospheric Dynamics

Advanced ionospheric current estimates by the Swarm constellation: A selection of representative results

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Motivation

Living Planet Symposium, Edinburgh, Sep. 2013

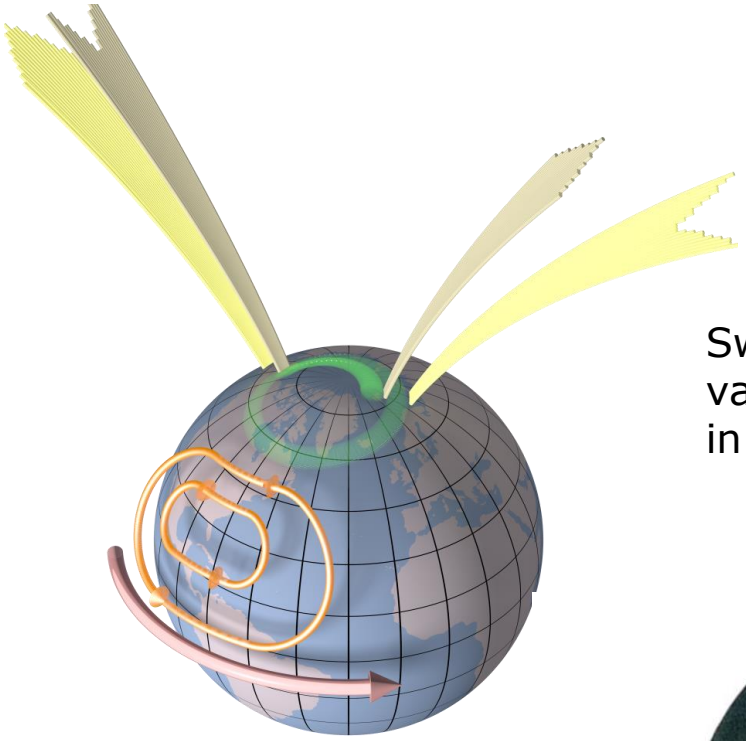
"Opportunities provided by the Swarm mission"

Two years into the mission

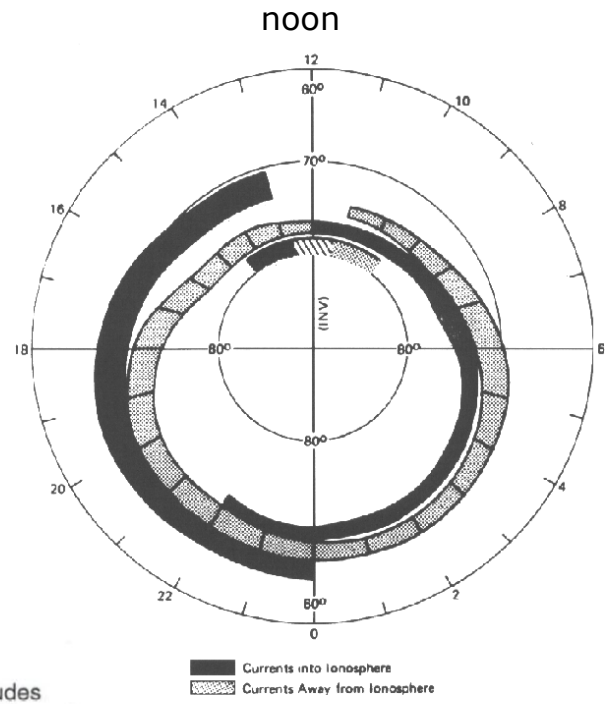
Field-aligned currents from lower pair are novel feature

Some interesting results have emerged

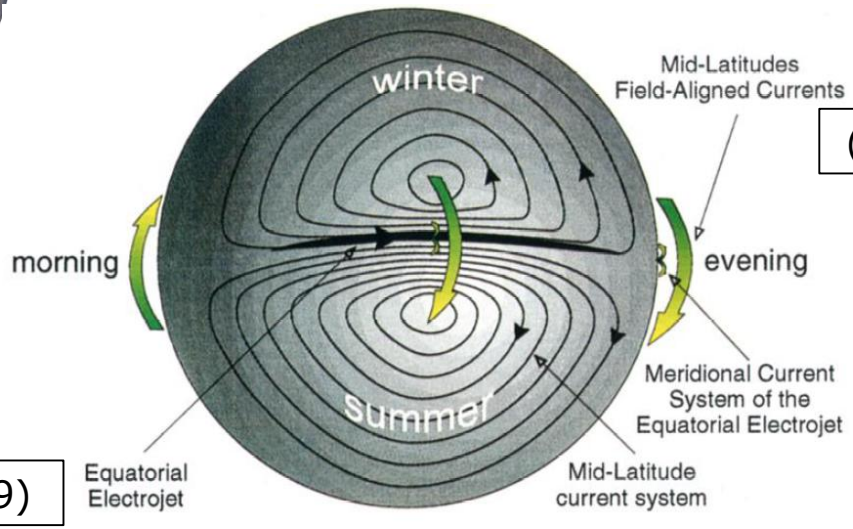
Current systems in the ionosphere



Swarm offers to study the various current systems in the ionosphere.



(Iijima and Potemra, 1976)



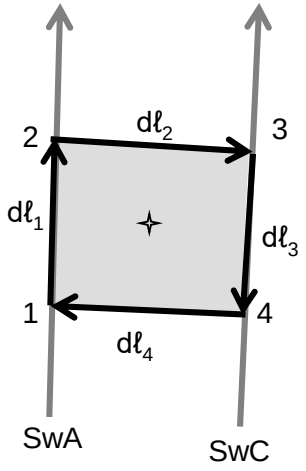
(Fukushima, 1979)

$$\mathbf{j} = \frac{1}{\mu_0 A} \oint \mathbf{B}\, d\lambda$$

Using Ampère's integral law in discrete form

$$j_z = \frac{1}{2\mu_0 A}\left[\left(Bx_{t_1} + Bx_{t_2}\right)d\ell_1 + \left(By_{t_2} + By_{t_3}\right)d\ell_2 - \left(Bx_{t_3} + Bx_{t_4}\right)d\ell_3 - \left(By_{t_4} + By_{t_1}\right)d\ell_4\right]$$

Integration area: $A = 0.25\left(d\ell_1 + d\ell_3\right)\left(d\ell_2 + d\ell_4\right)$



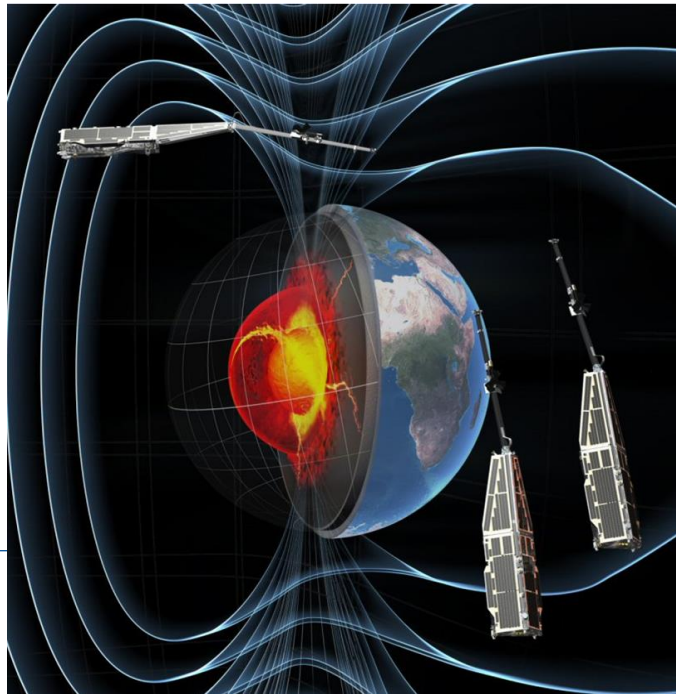
Ritter et al., 2013

Along-track variation, B_X, is derived from two subsequent measurements

$dt=5sec \rightarrow dl_{1,3}=38km$

Cross-track separation is 1.4° in longitude (50 km @ 70°).

Vertical current, j_Z, is projected on the field direction to get FAC.

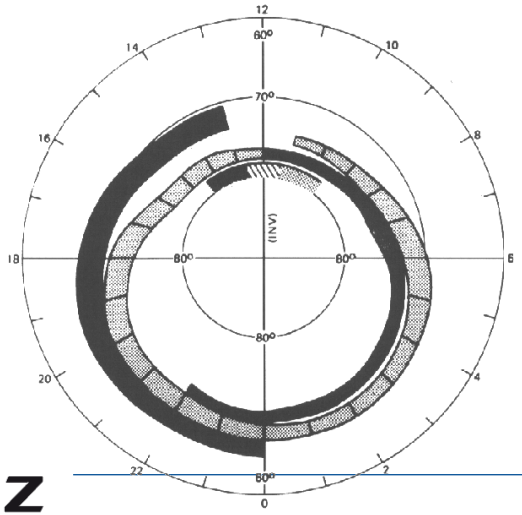


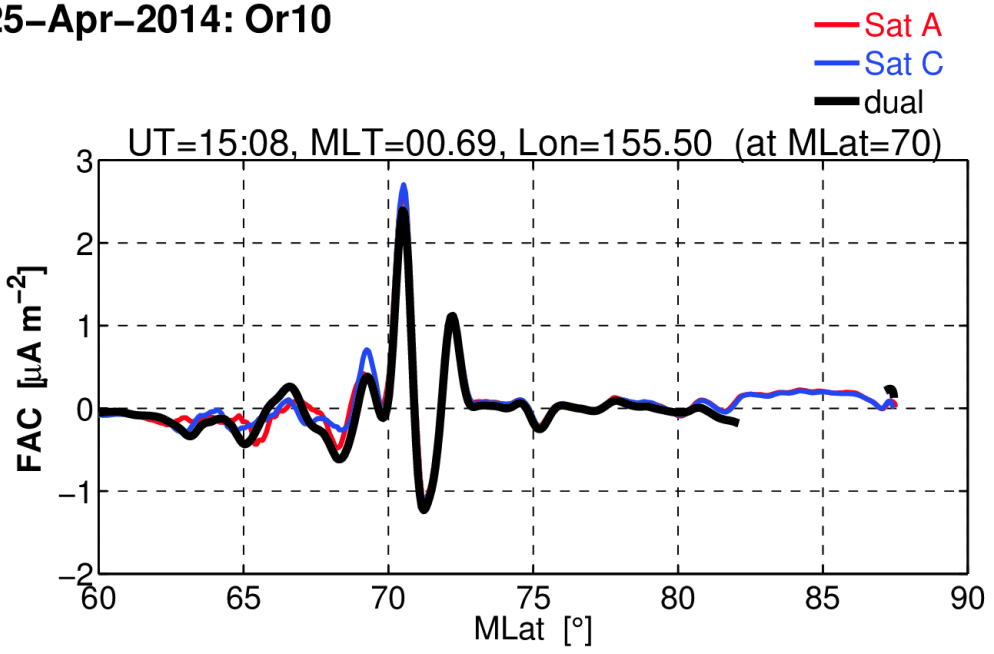
FAC example, auroral oval

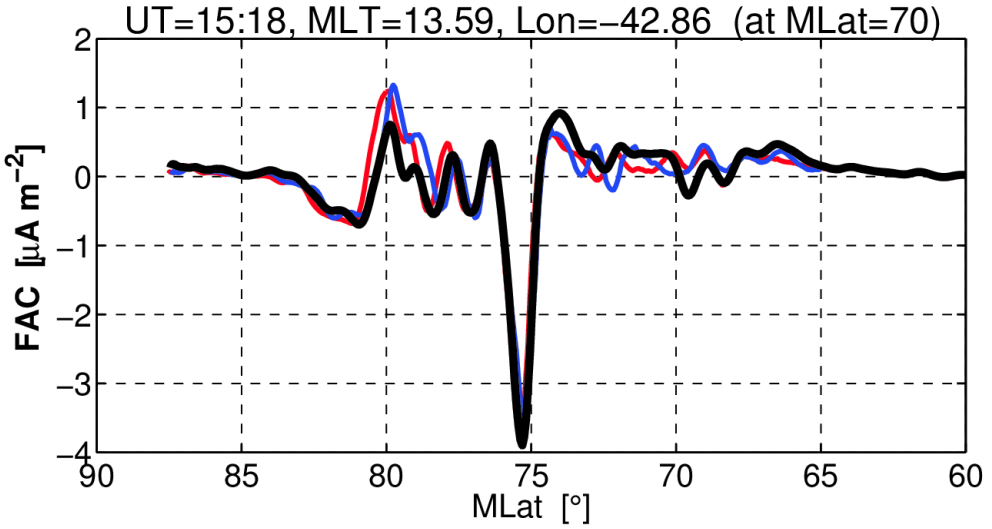
Example from midnight (3-sheet) and afternoon (strong R1).

Generally single and dual-satellite FACs agree very well in the auroral region,
and there is low FAC activity in the polar cap.

<u>Note:</u> Positive values reflect downward FACs in NH.

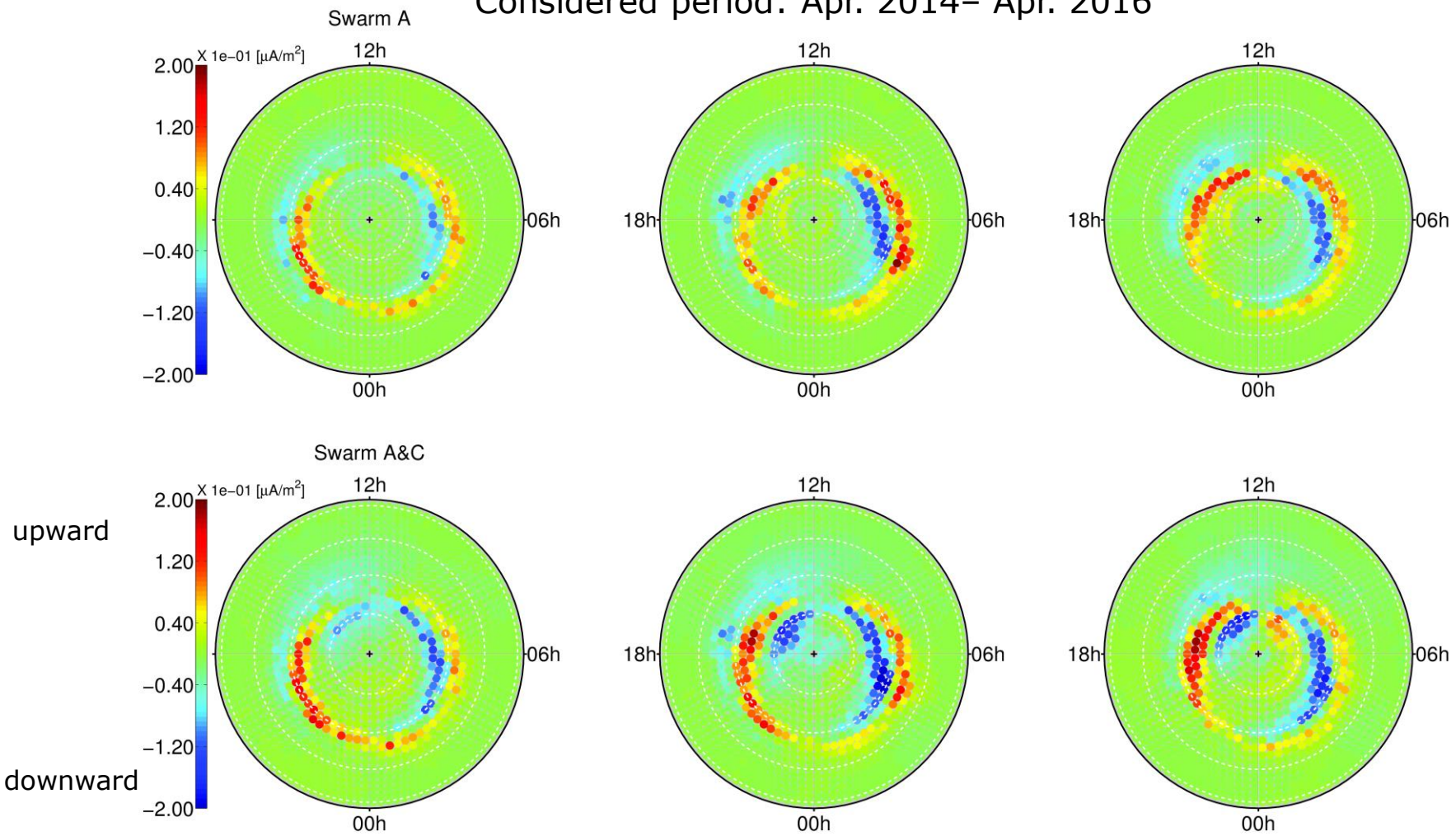






FAC comparison: single, dual-satellite; Northern hemisphere (averages)

Considered period: Apr. 2014– Apr. 2016



FAC comparison: single, dual-satellite; Southern hemisphere (averages)

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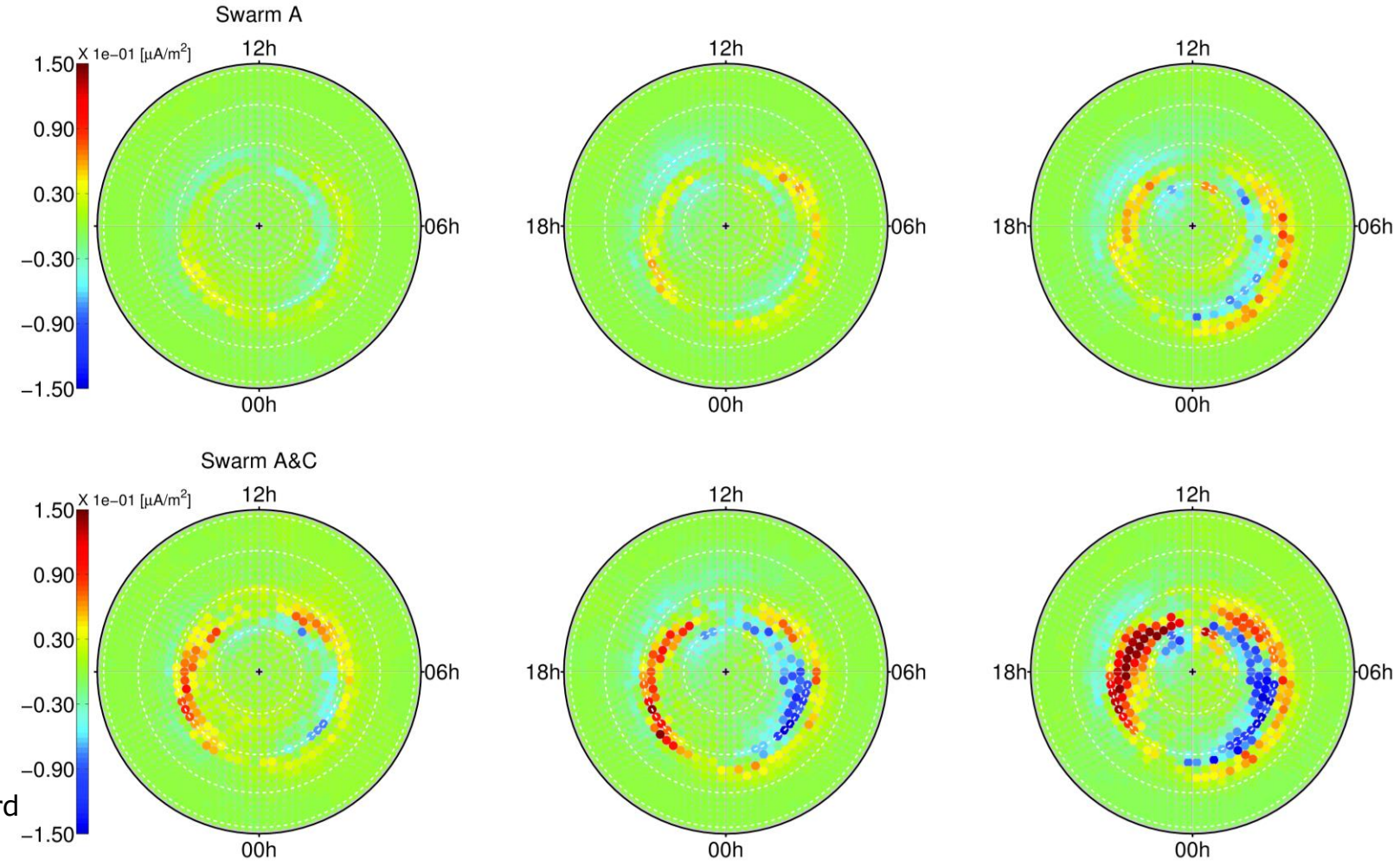
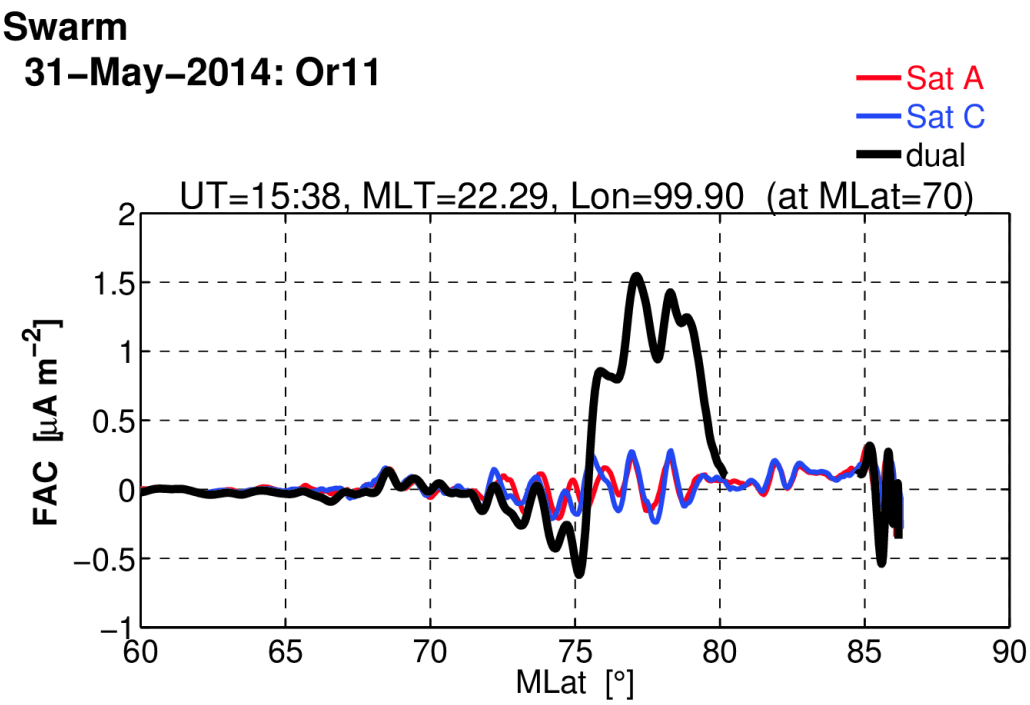
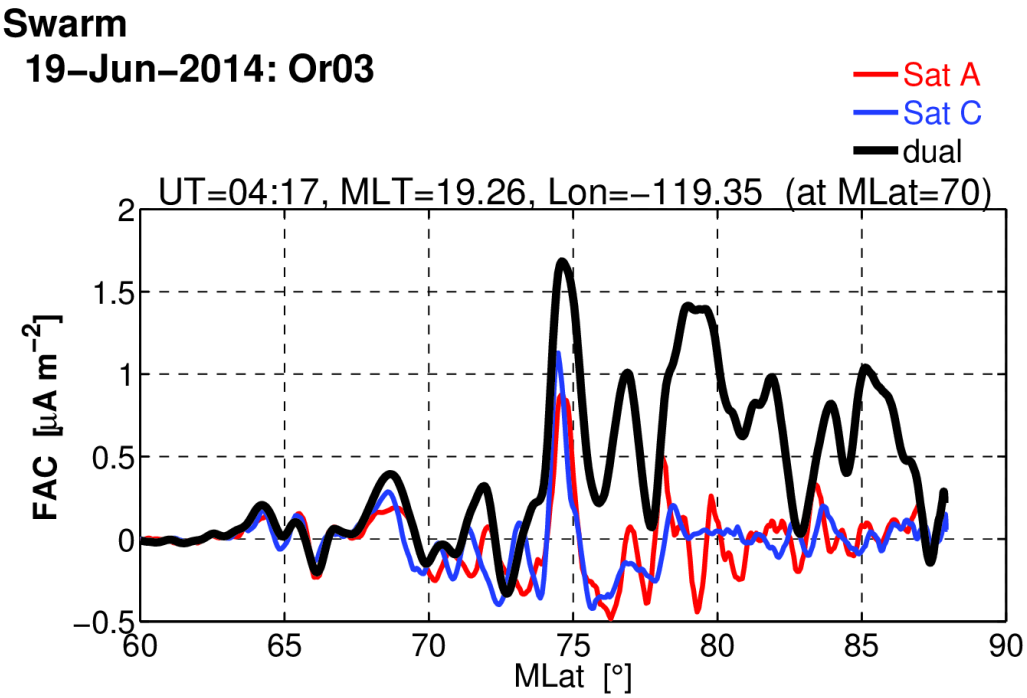


FAC examples of mismatch

In the polar cap we find occasionally significant differences between single and dual-satellite FAC estimates.

The occurrence of events with differences is not randomly distributed.

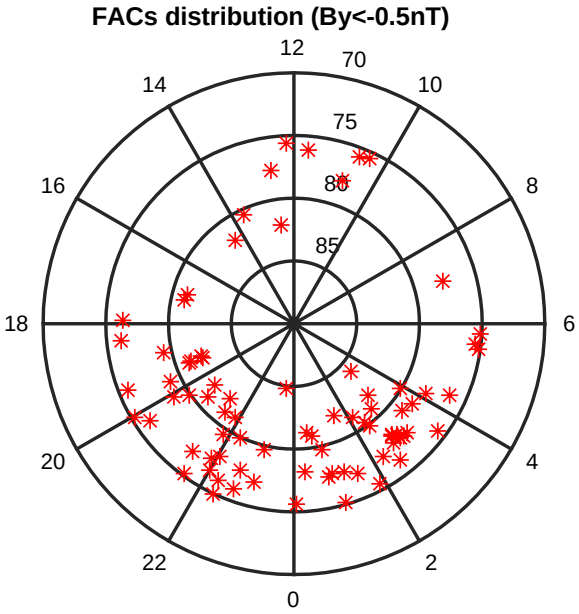


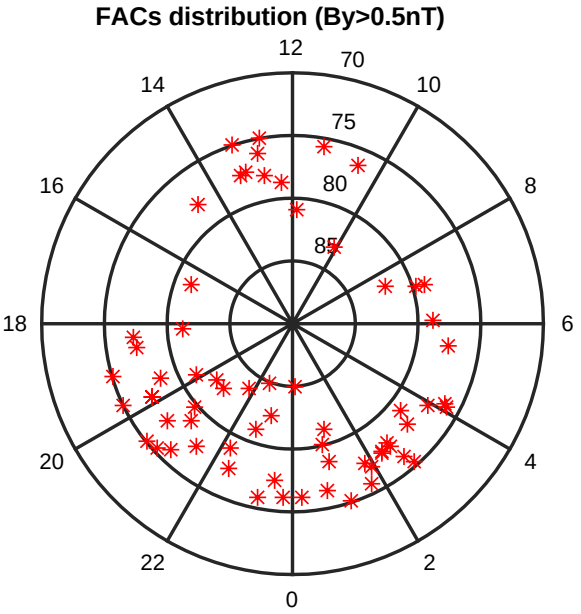


Event distribution

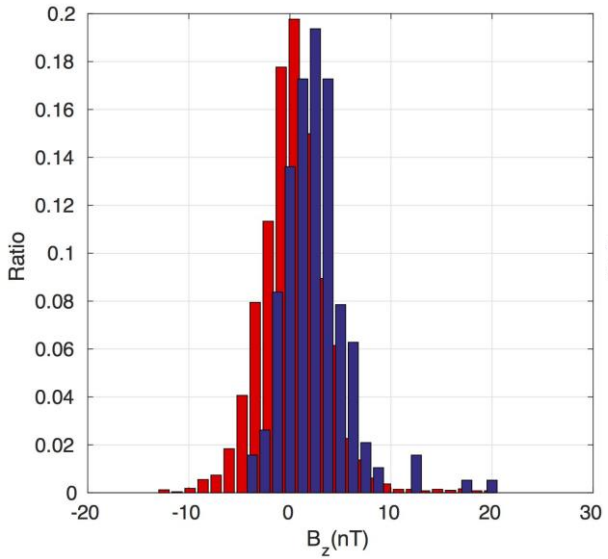
Events of single/dual mismatch occur preferably on the nightside.

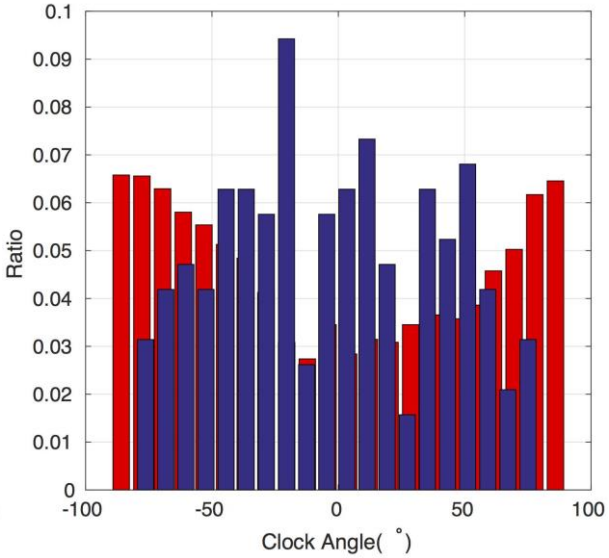
There is no obvious dependence on IMF *By.*



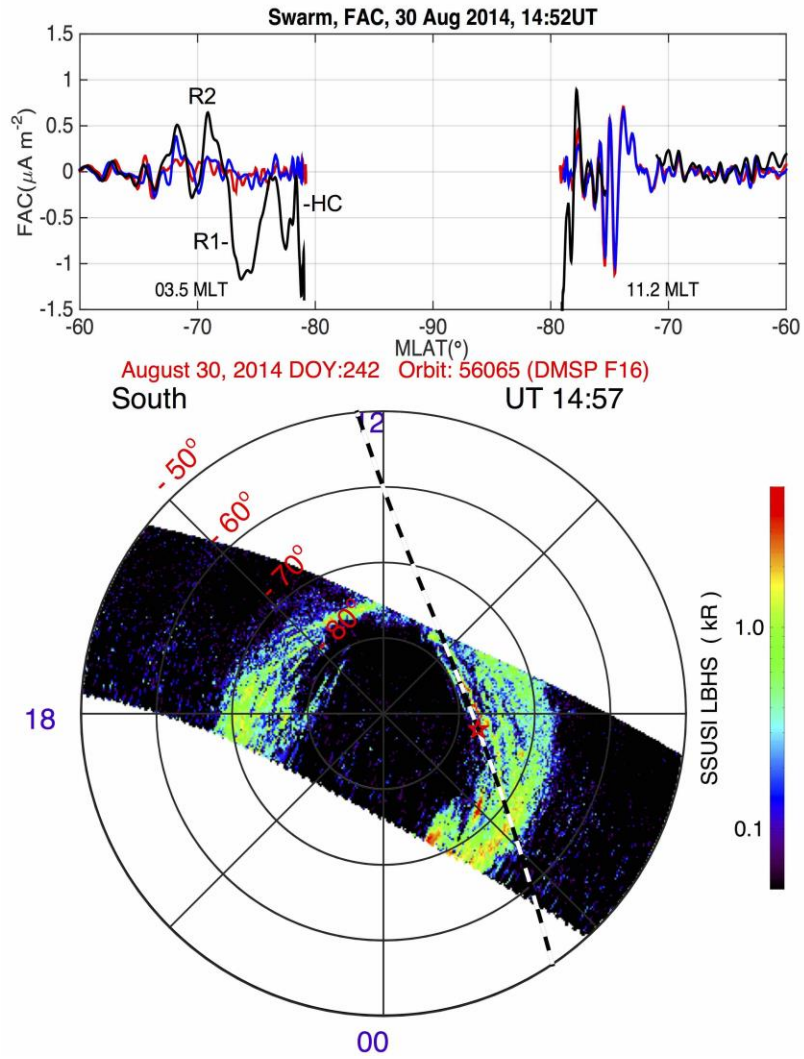


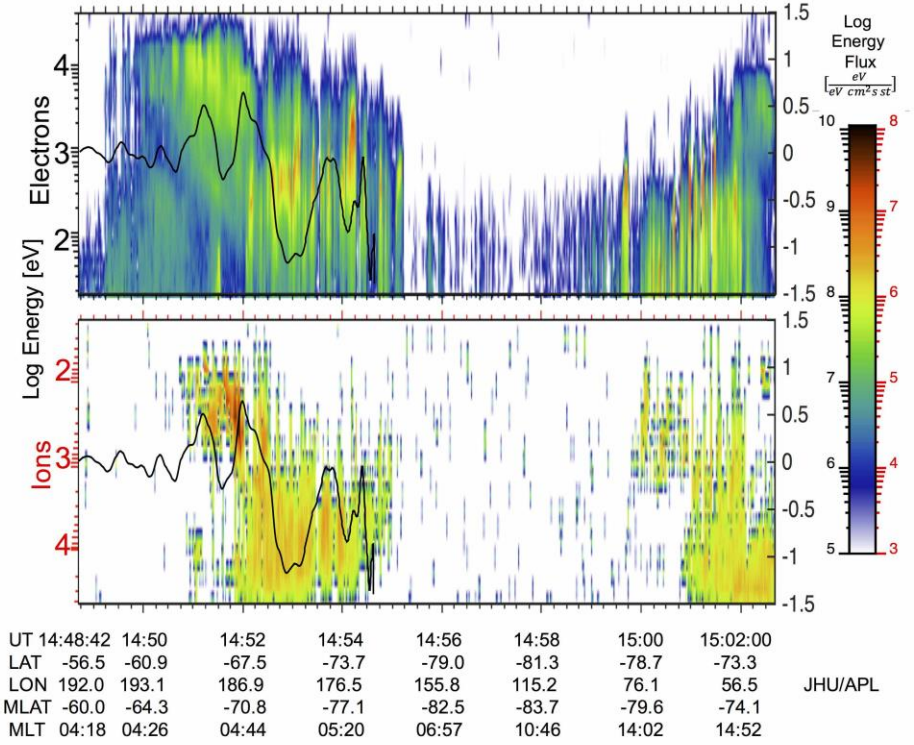
Our polar cap FACs occur preferably during northward IMF (positive *Bz*).
red: normal distribution, blue: event distribution.





Composite plot of a high-latitude FAC event, Southern hemisphere

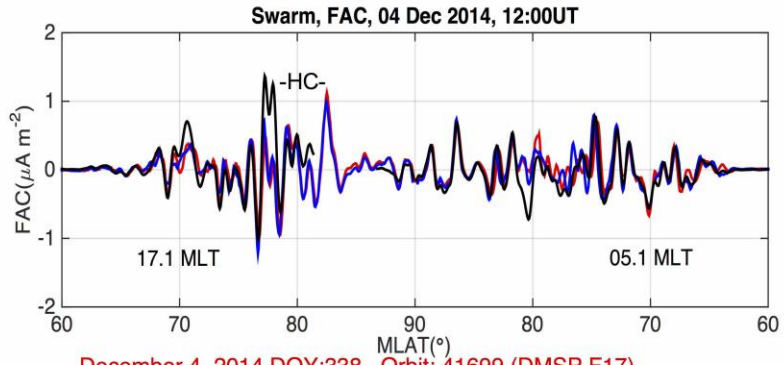


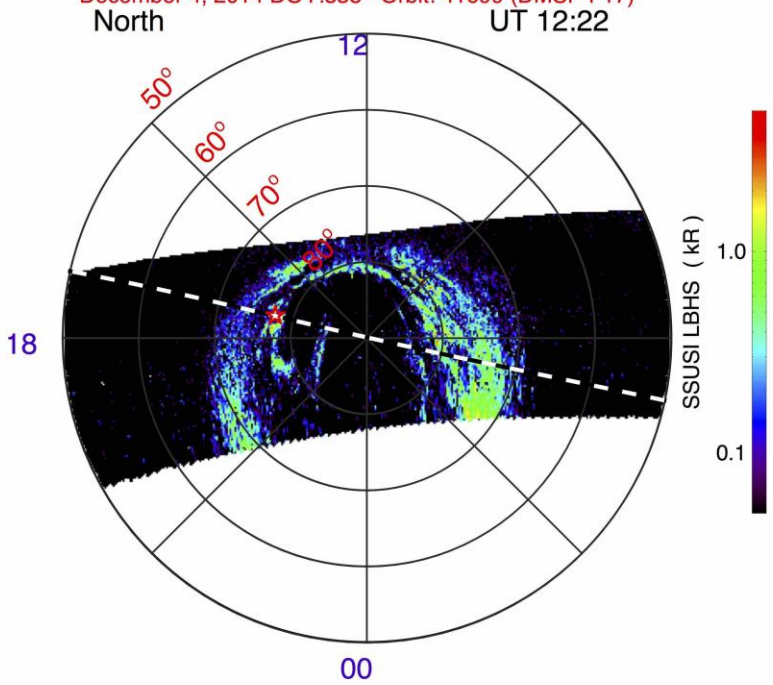


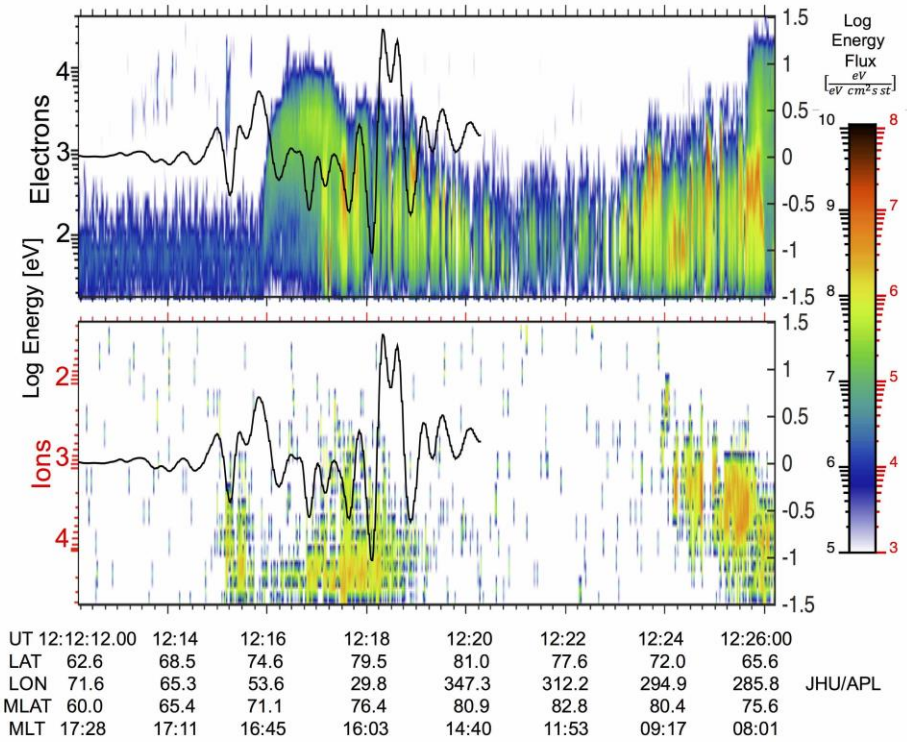
DMSP spectrograms show clear signs of precipitation associated with FACs.

Swarm skims the auroral oval.
Single satellites cannot resolve FACs.

Composite plot of a high-latitude FAC event, Northern hemisphere







Sun-aligned auroral features are accompanied by FACs.

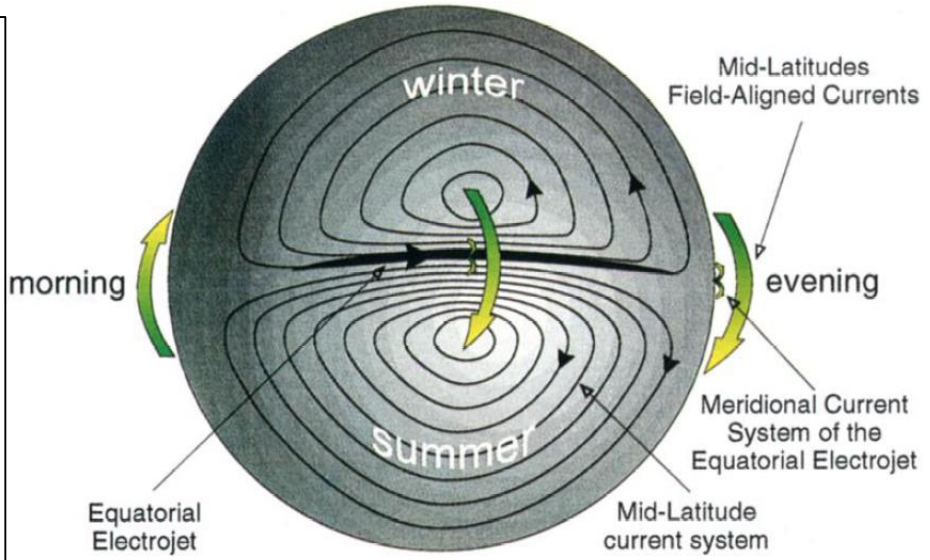
Electron spectra suggest FAC filaments on closed field lines.

Mid-latitude current systems, Inter-hemispheric field-aligned currents

Also at mid latitudes there is current flowing, e.g. the Sq current system, comprising vortices in the two hemispheres on the dayside with opposite senses of rotation.

In case of potential differences between the hemispheres FACs will flow.

Swarm allows for the first time to measure these inter-hemispheric FACs directly.



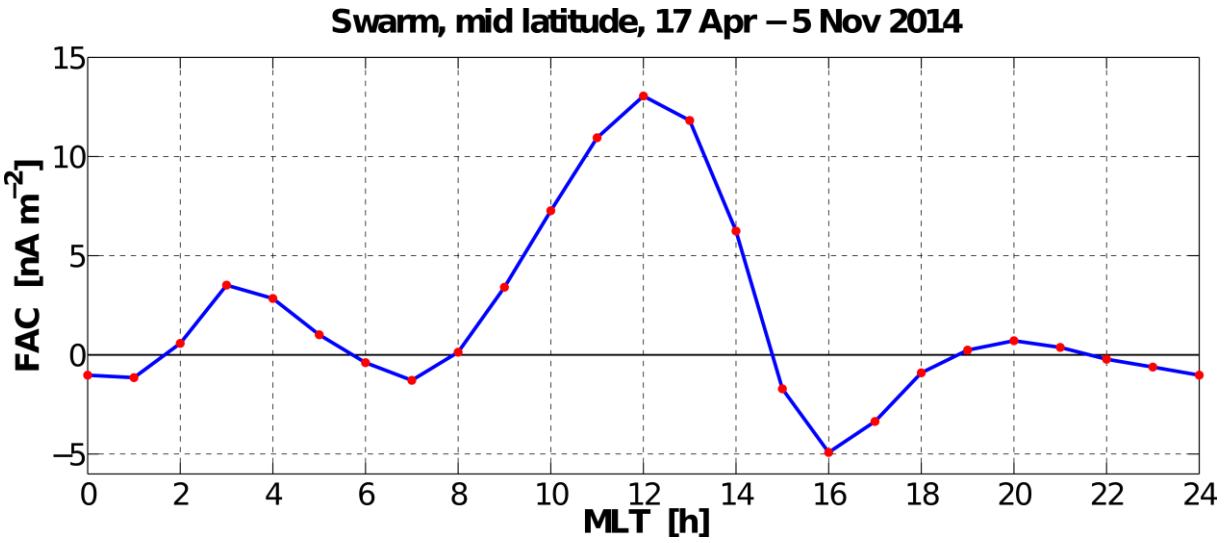
(Fukushima, 1979)

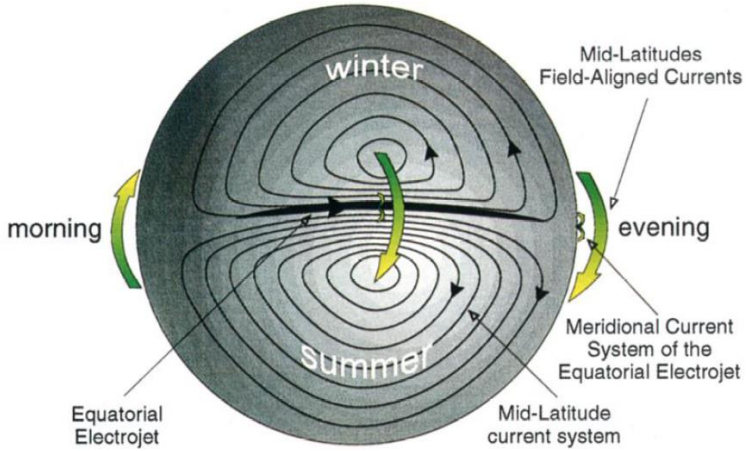
Local time variation of inter-hemispheric field-aligned currents

We find the main current, as expected around noon from the winter to the summer hemisphere.

During morning and evening hours currents flow in the opposite direction.
In the evening this is different from prediction.

Somewhat surprising is the the northbound current around 03 MLT.

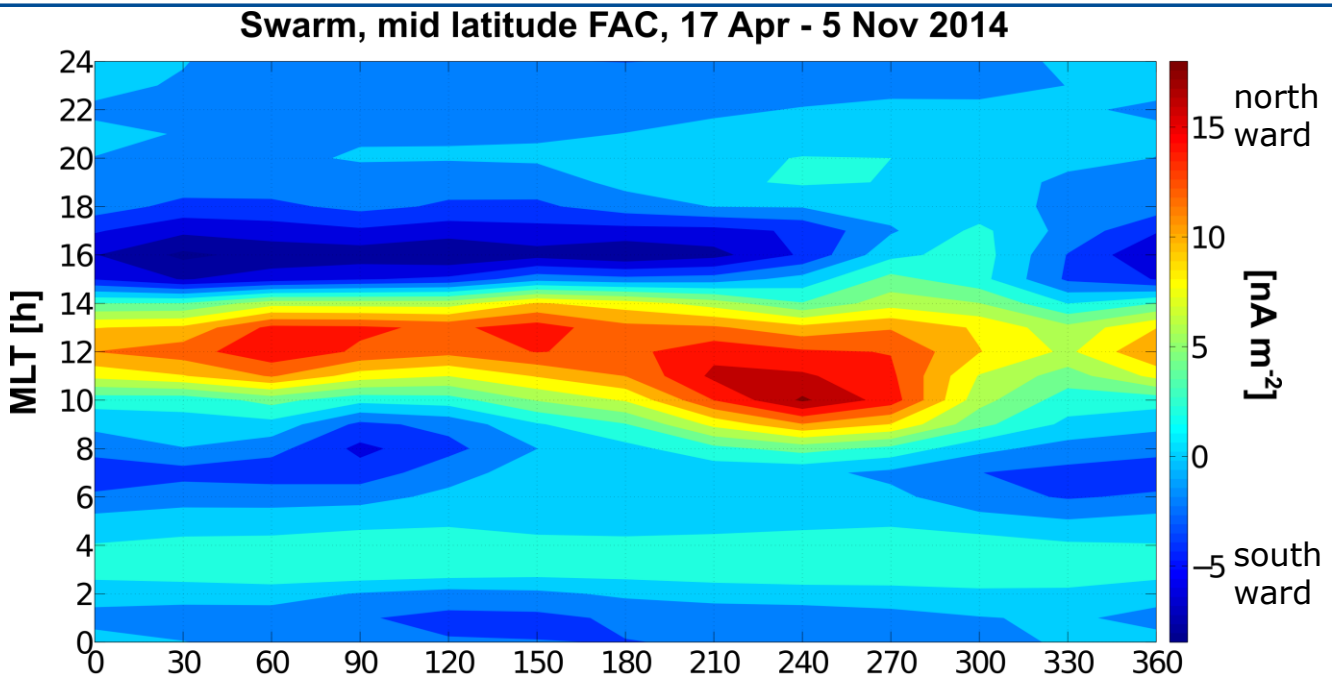




Longitude distribution of inter-hemispheric FACs, June solstice

The IHFACs from Swarm show a distinct longitude distribution.

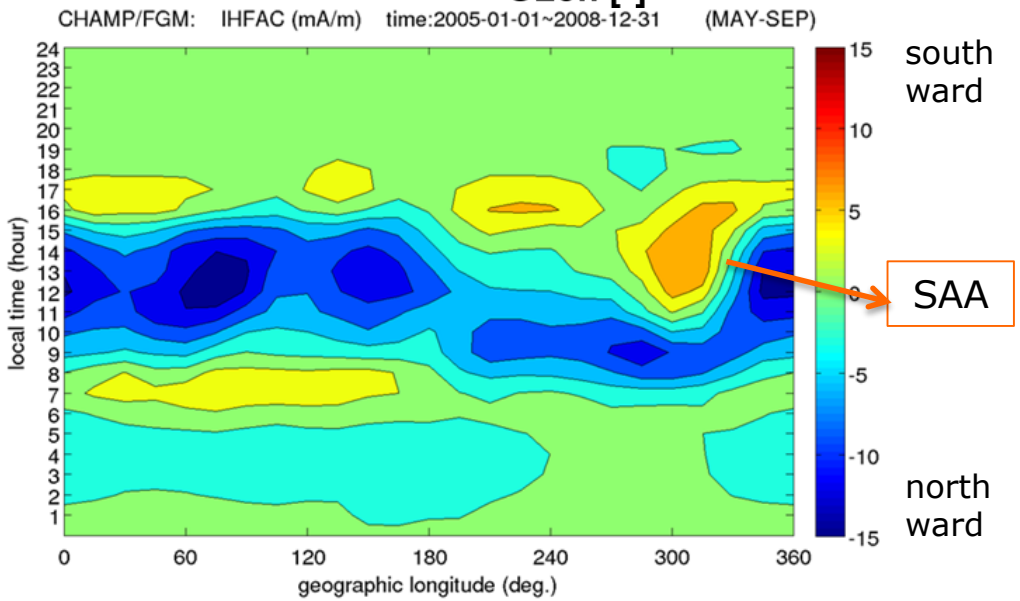
Around 330° longitude the noon-time FAC is week.



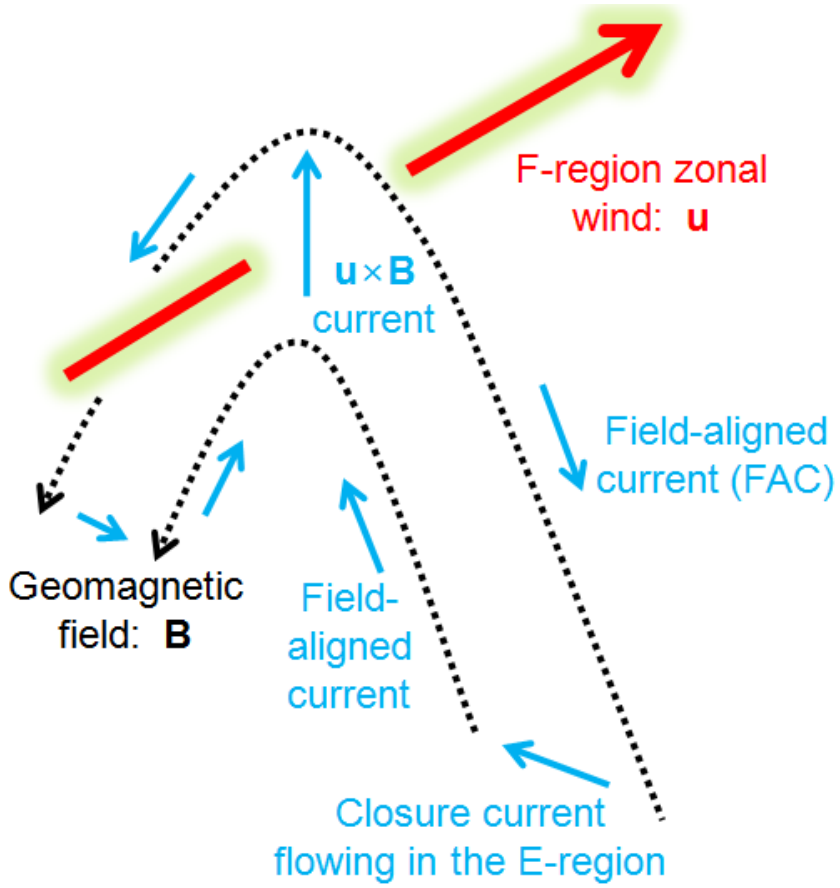
The IHFACs from CHAMP agree in general with those from Swarm.

The anomalous distribution around 330° E is related to the SAA.

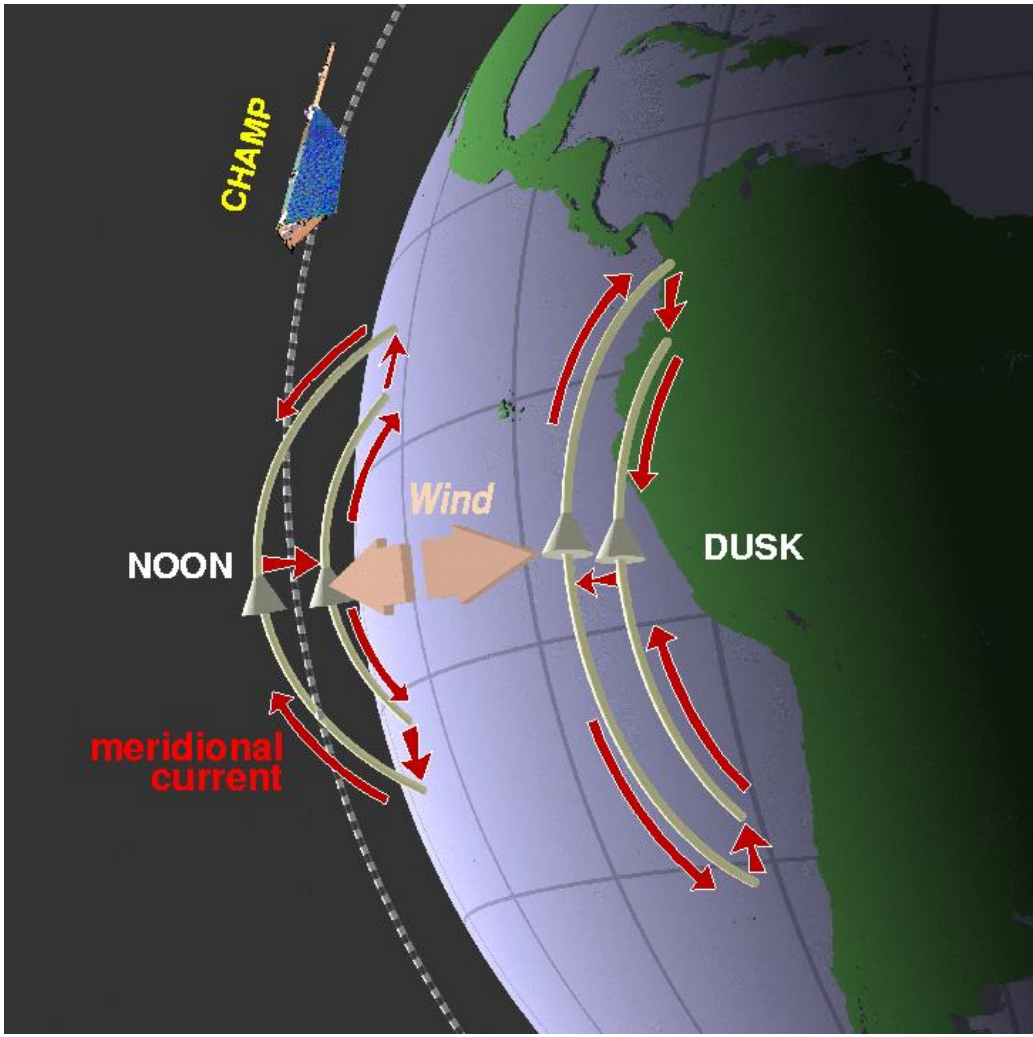
(Park et al., 2011, AnnGeo)



The wind-driven dynamo in the F-region



Concept of wind-driven dynamo
Rishbeth (1972)

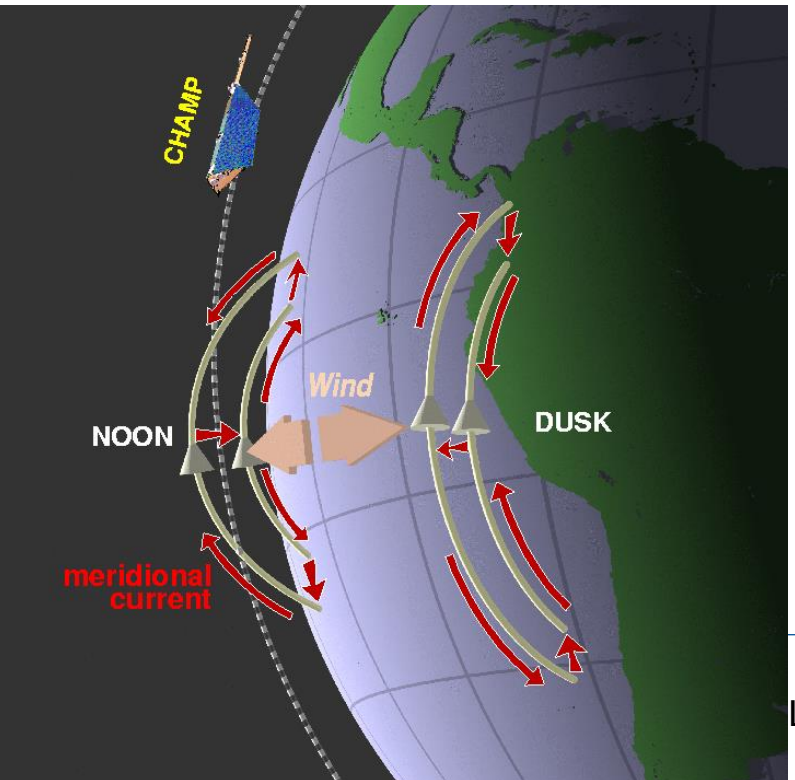


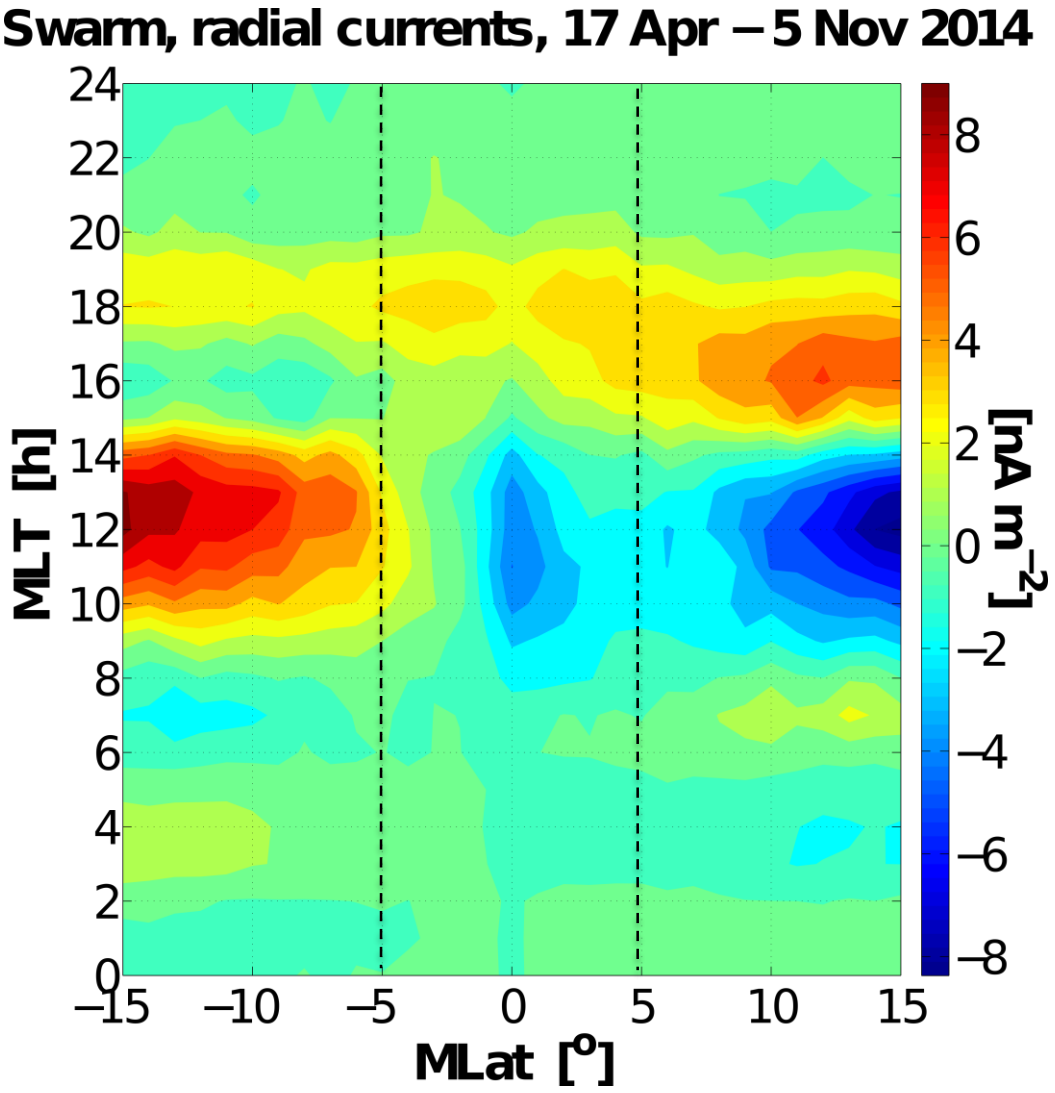
CHAMP analysis: Lühr and Maus (2006); Park et al. (2010)

Swarm radial currents at low latitudes

At low latitudes IHFACs appear as radial currents with opposite signs in the two hemispheres.

Right above the equator there are weak downward currents around noon and upward in the evening.

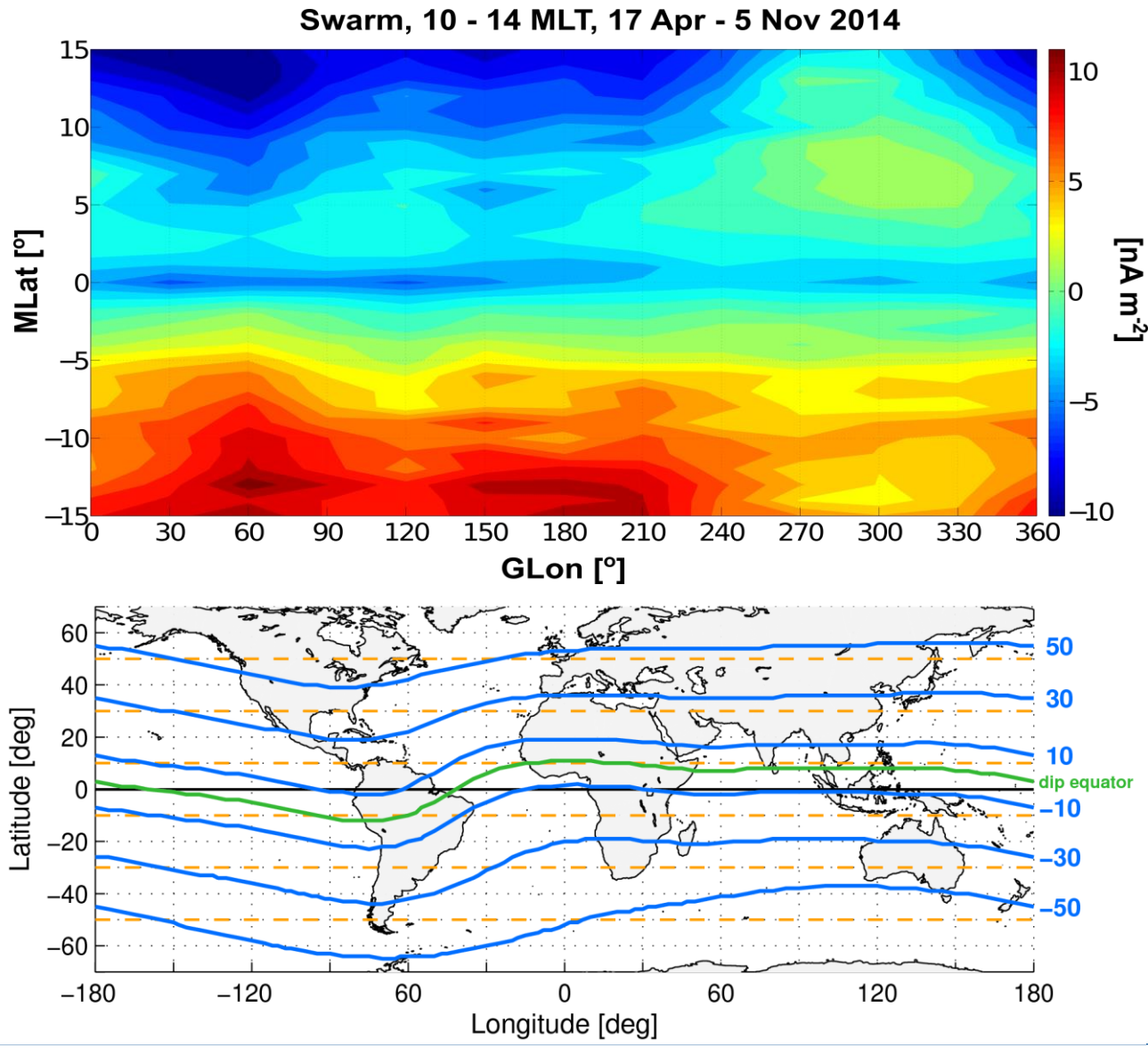




Longitudinal distribution of noon-time radial currents at equator

The vertical currents around noon-time are stronger in the 0˚ - 180˚ longitude sector.

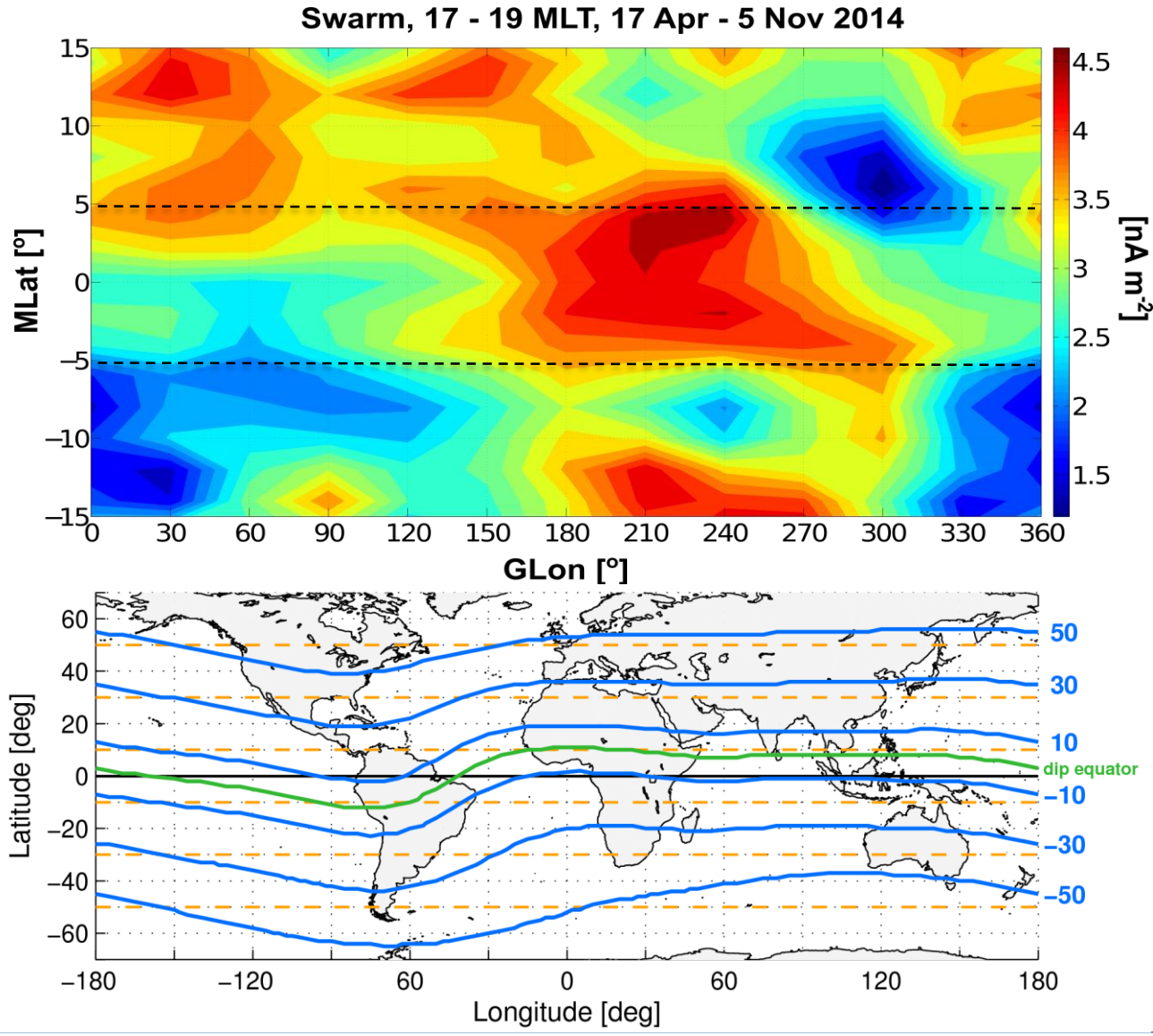
Over that range the dip-equator is located in the northern (summer) hemisphere, i.e. higher ionospheric conductivity.



Longitudinal distribution of evening radial currents at equator

During the evening hours the equatorial radial current is strongest in the 160° E- 290° E sector, over the Pacific Ocean.

Here the geomagnetic field has an eastward declination, and fluxtubes are well aligned with the evening terminator during summer.



Zonal current measurements

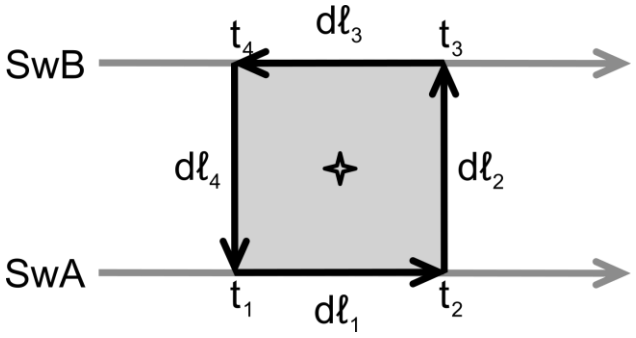
During the early mission period, when all three Swarm spacecraft are still close together, the constellation can be used to estimate zonal currents flowing between the higher and lower satellites.

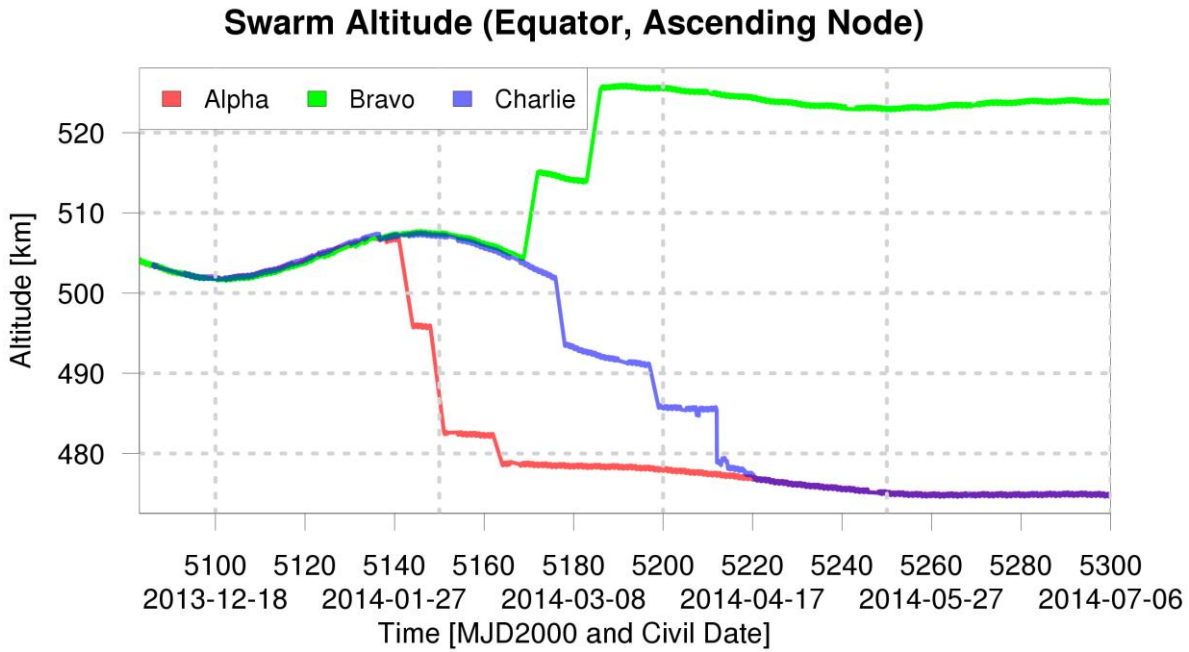
Such currents may degrade field models derived from different altitudes.

Swarm configuration for zonal current measurements

The same approach as for the radial currents has been used between the upper and lower spacecraft for estimating zonal currents.

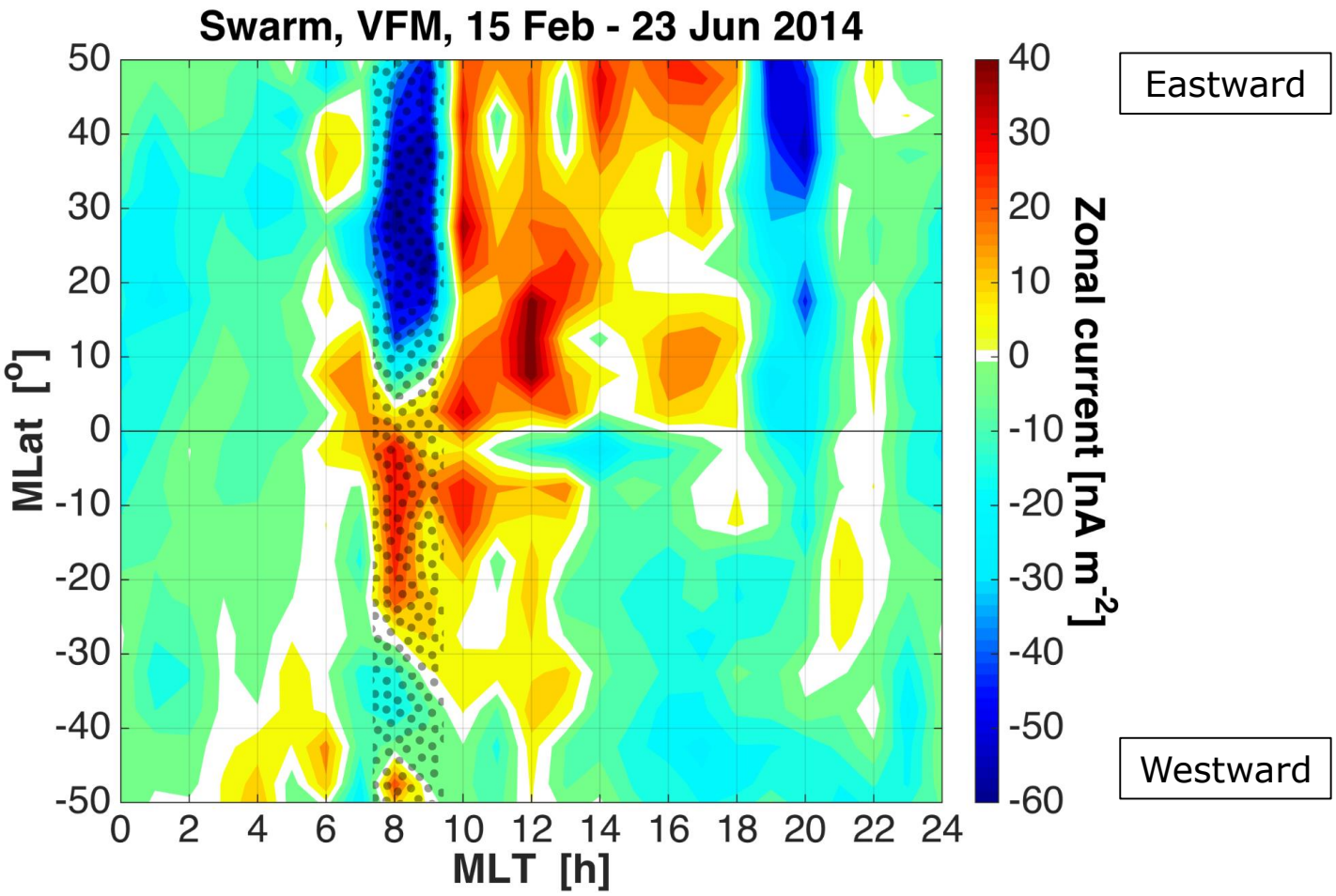
During February 2014 Swarm B and C flew at same altitude. Two independent current estimates with respect to Swarm A could achieved.





Swarm satellites altitude evolution.

Mean zonal currents at 490 km altitude

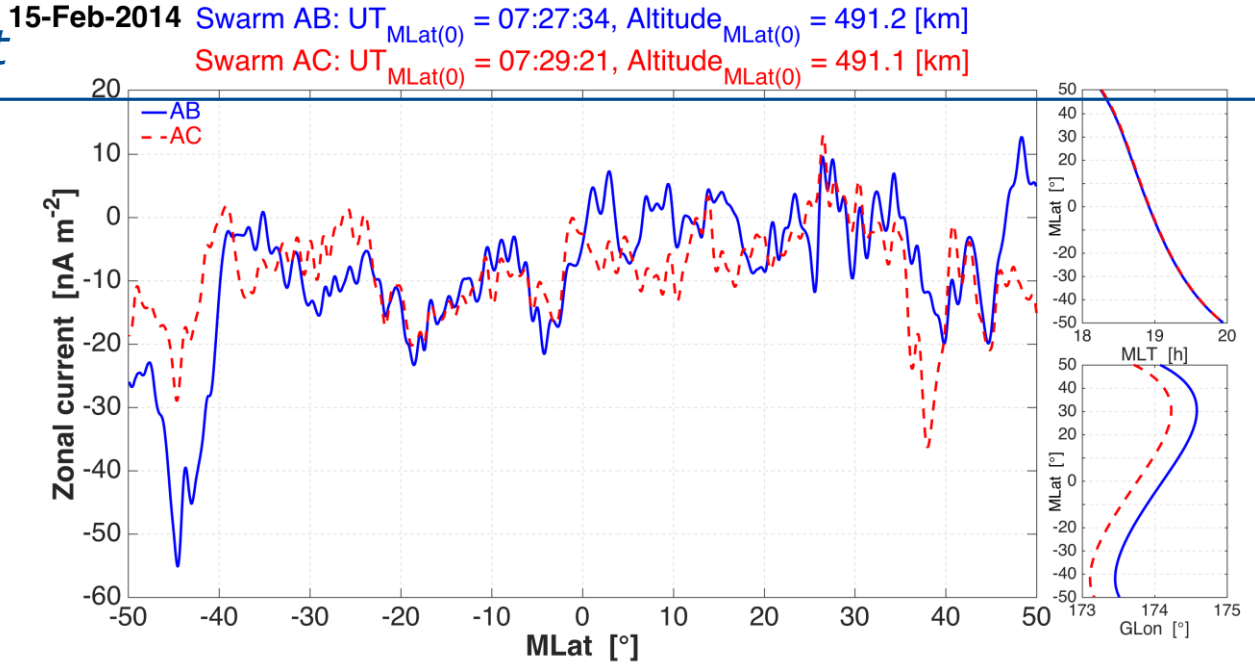


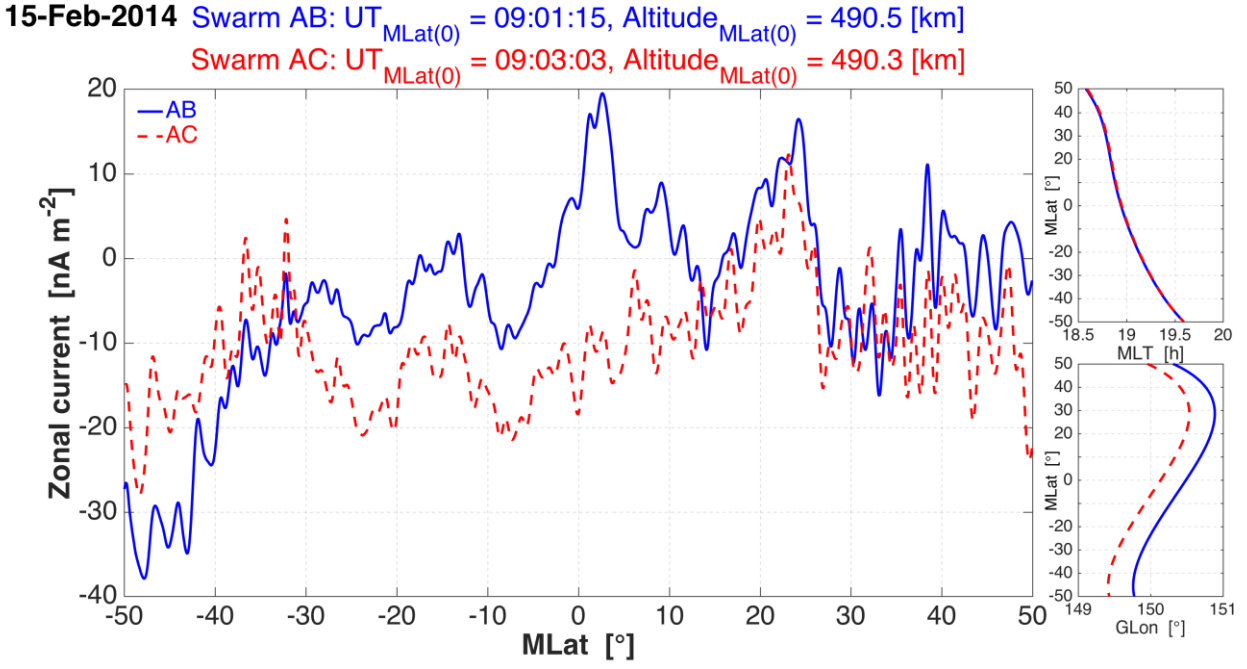
Variability of zonal current

The mean zonal currents are rather weak, but the variability in time and space is quite large.

Recordings of the red and blue curves are separated by only 2 min in time and 50 km in longitude.

Atmospheric gravity waves are believed to be the driver for the fluctuations.





GFZ Helmholtz-Zentrum Potsdam

Summary and Conclusions

- The Swarm constellation mission proved to be well suited for determining various kinds of ionospheric currents.
- The dual-satellite approach provides reliable field-aligned current (FAC) estimates. In the polar cap region many FACs have been missed by previous missions.
- At mid latitudes inter-hemispheric field-aligned currents (IHFAC) have been detected, flowing from the winter to summer hemisphere around noon and in the opposite direction during morning and evening.
- The F-region wind dynamo causes downward currents above the equator around noontime and upward currents in the evening.
- Zonal currents in the top-side ionosphere have been quantified. They are eastward directed at daytime and westward at night. Temporal and spatial variability is very high, probably caused by atmospheric gravity waves.