Space Weather Monitoring by Swarm Magnetic Field Observations: The SFAC Index

Adrian Blagau (1), Octav Marghitu (1), Vlad Constantinescu (1), Malcolm Dunlop (2), Guram Kervalishvili (3), Matthew Friel (4)

(1) ISS Bucharest, Romania; (2) RAL Space, STFC, UK; (3) GFZ Potsdam, Germany; (4) JHU-APL, Maryland, USA

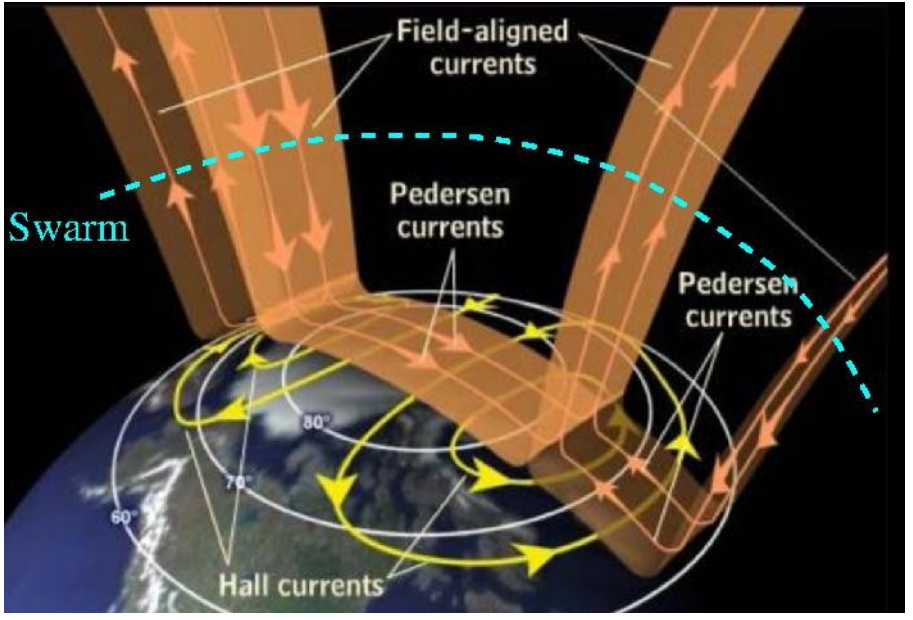
Swarm 10 Year Anniversary & Science Conference, 8-12 April 2024, Copenhagen, Denmark

The SFAC index

SFAC index has been introduced in the SWESMAG (Swarm-DISC) project:
addresses the use of Swarm magnetic field data for the investigation of SWE effects

Swarm mission is suitable to study SWE effects:

- provides direct observation of the FAC system:
  - connects distant M-sphere with ionosphere
  - dB perpendicular to B
- monitors from above the polar electrojet (PEJ):
  - ionospheric (Hall) current system
  - signature in dB along B or B intensity
- offers numerous conjunctions with ground-based observatories (GBOs):
  - dB on ground caused mainly by PEJ (Fukushima 1976)
  - dB/dt cause GICs and related SWE effects



After COMET program, UCAR, https:// www. comet. ucar. edu/

The SFAC index has been proposed:

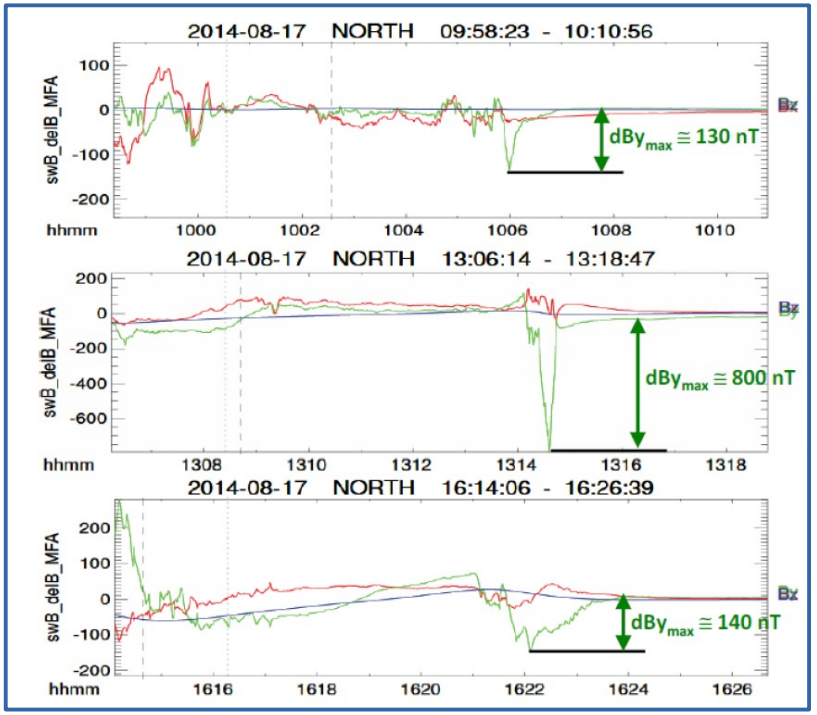
- to help the characterization of the 3D ionospheric current system
- for monitoring the risk of intense and potentially harmful GICs

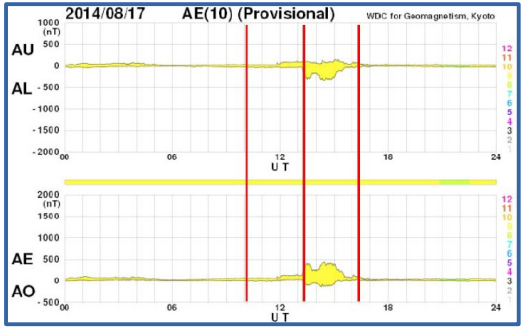
The SFAC index

SFAC definition:

- the maximum (absolute) dB during AO crossing by Swarm
- quantifies the large-scale FAC system
- easy to compute => can be easily provided (near real-time)

For a quasi-planar FAC sheet perpendicular to s/c orbit, SFAC scales with the (total) sheet current (integral of the FAC density)



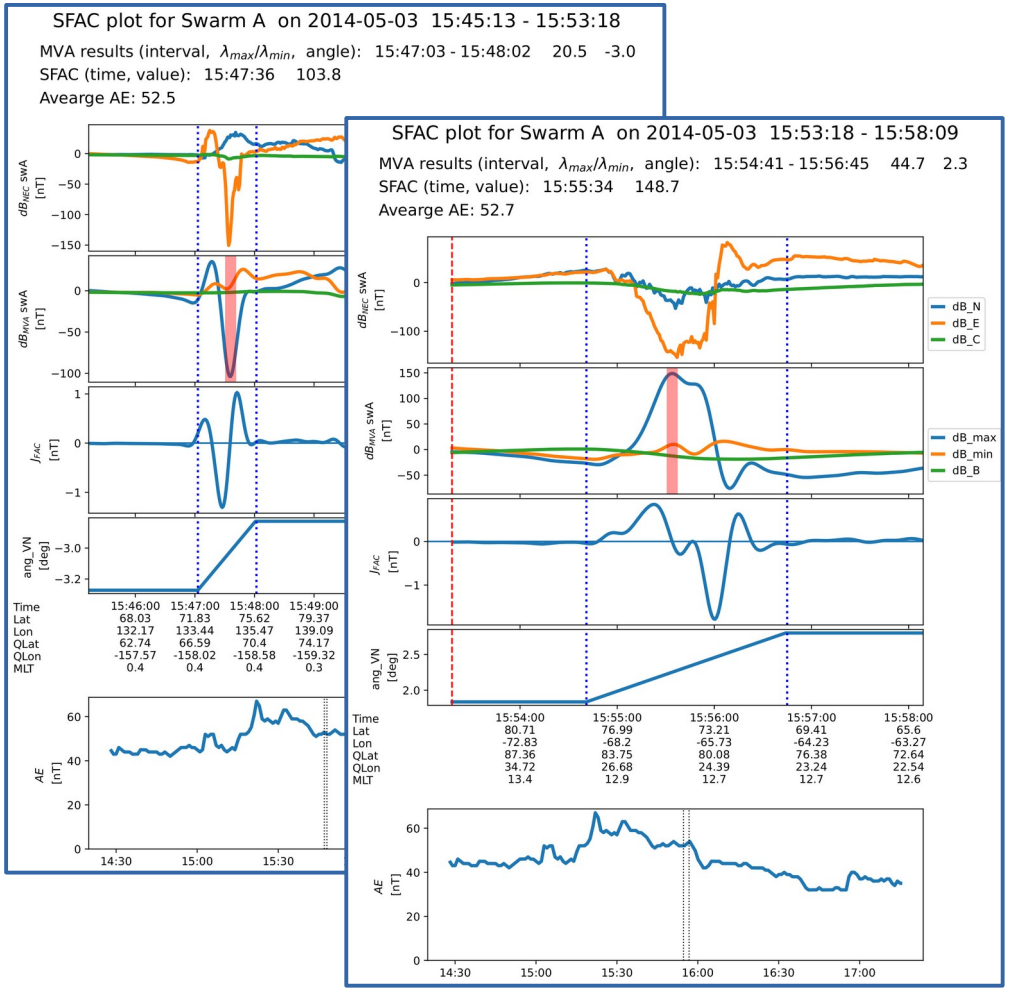


To roughly illustrate the SFAC behavior: *Top:* Successive AO crossings by Swarm on Aug. 17, 2014, before, during, and after a substorm. Maximum of dB varies from 130 nT to 800 nT and back. *Bottom:* AE index.

We studied SFAC index statistically

- **Swarm data: 17.04 – 31.12 2014**
- **Two complete MLT coverage by Swarm orbit**
- **We compare SFAC with AE and PEJ indices, and with GBO data**

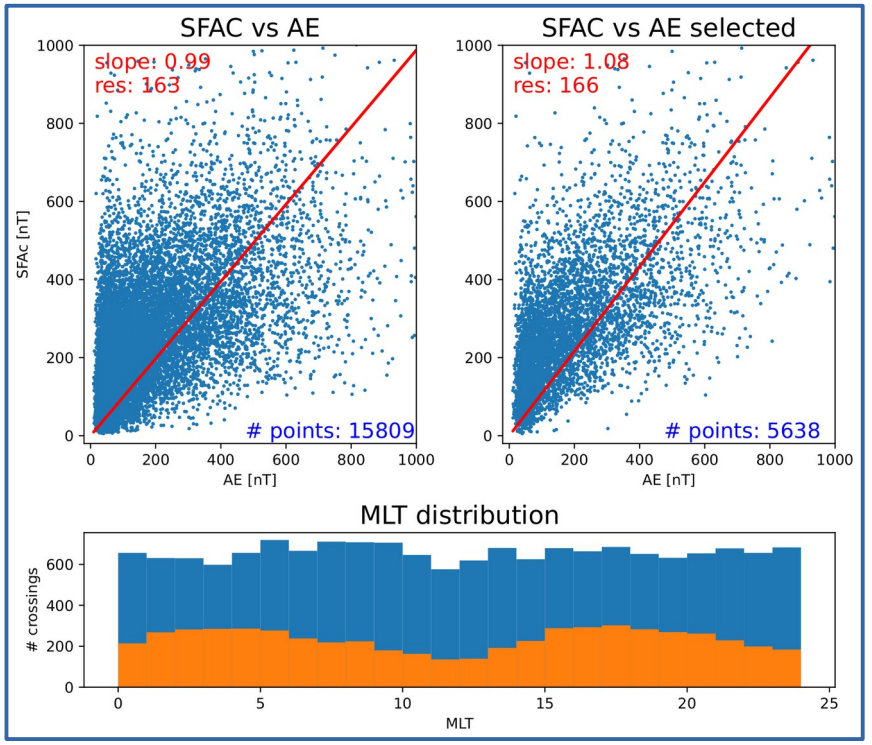
SFAC determination



To construct the data base, for each quarter orbit we computed SFAC:

- Current density is computed from filtered dB
- The AO interval is automatically identified
- MVA is applied and dB is transformed in MVA related frame
- SFAC is identified as maximum of dBmax
- Standard plot is produced for verification:
  - dB in NEC
  - dB in MVA frame
  - current density
  - Inclination
  - AE index for a larger interval

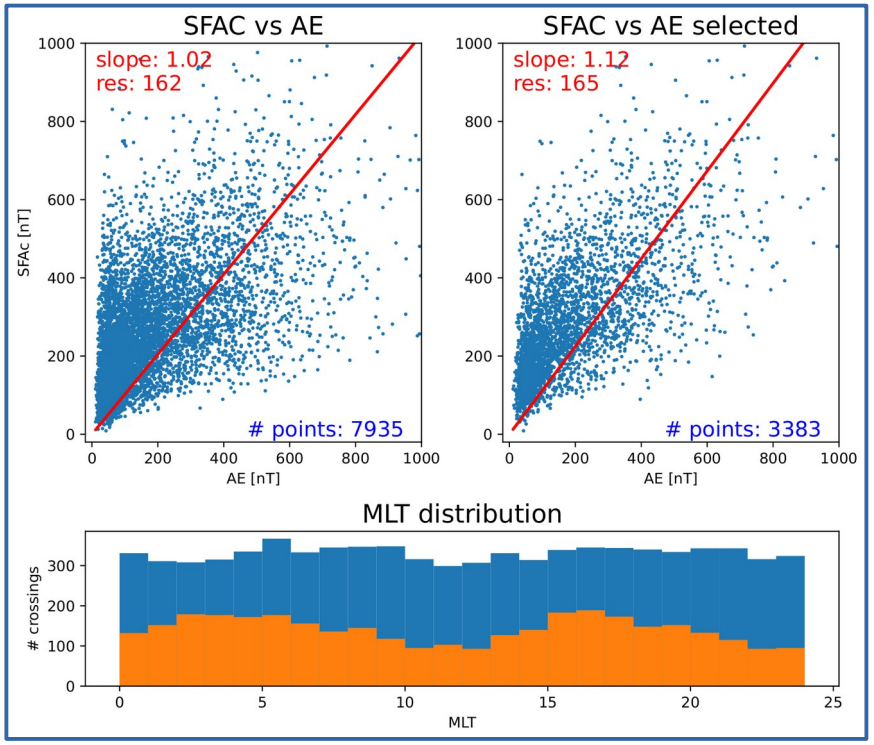
SFAC vs AE comparison



SFAC vs AE comparison:

- Left: all points/all q-orbits. Poor correlation; many points with small AE values
- Around 600 points in each hour of MLT (bottom)
- Right: the correlation does not improve significantly if planar + well inclined current structures are selected (MVA eigenvalues ratio > 10. Inclination < 30 deg)

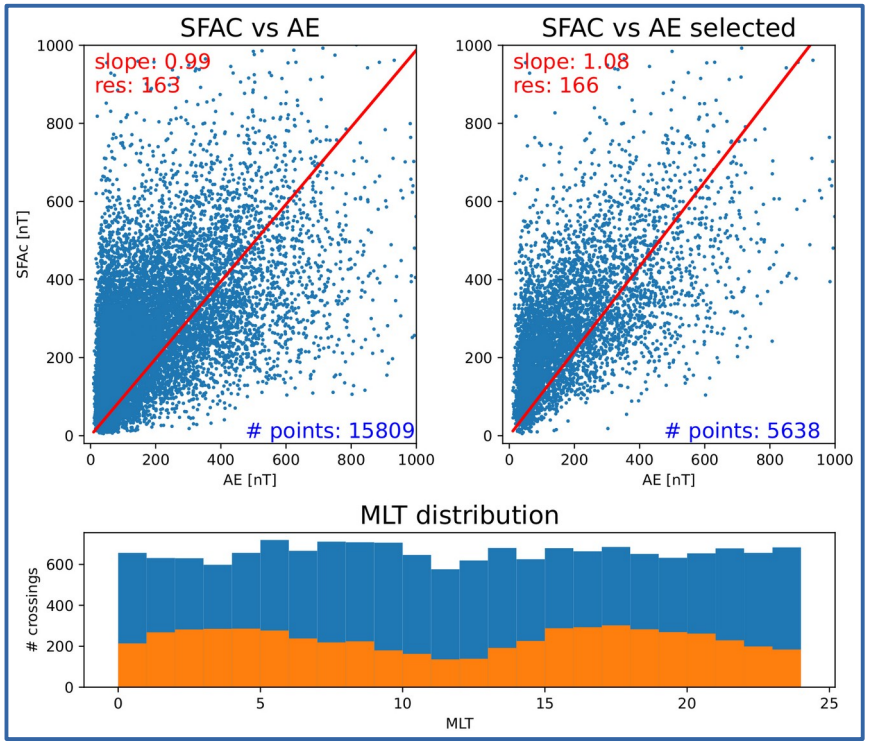
SFAC vs AE comparison



SFAC vs AE comparison:

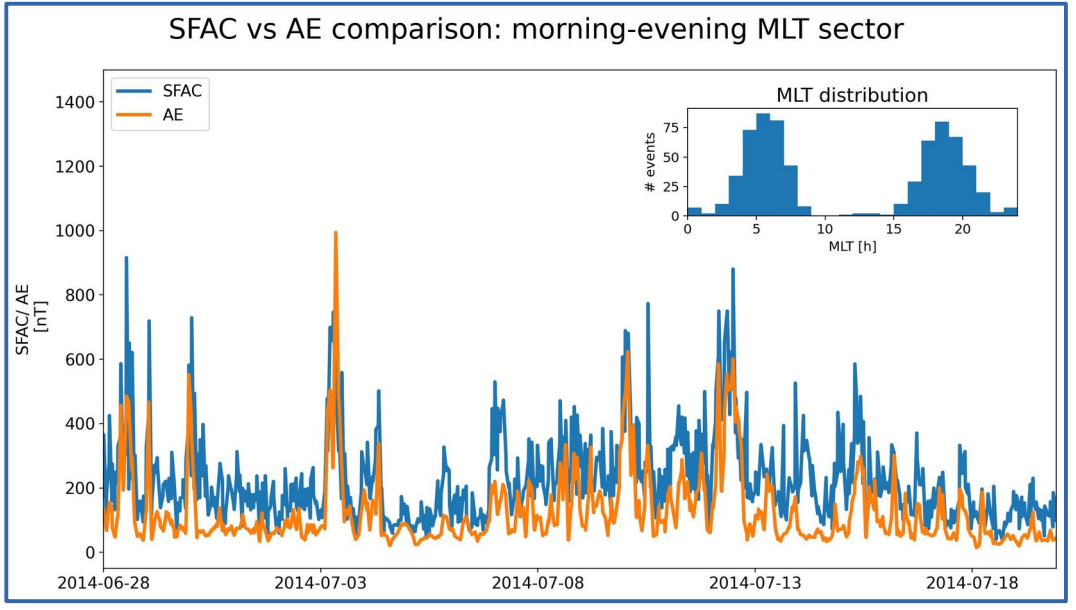
- Left: all points/all q-orbits. Poor correlation; many points with small AE values
- Around 600 points in each hour of MLT (bottom)
- Right: the correlation does not improve significantly if planar + well inclined current structures are selected (MVA eigenvalues ratio > 10. Inclination < 30 deg)
- Same conclusion when only N hemisphere is selected

SFAC vs AE comparison



SFAC vs AE comparison:

- Left: all points/all q-orbits. Poor correlation; many points with small AE values
- Around 600 points in each hour of MLT (bottom)
- Right: the correlation does not improve significantly if planar + well inclined current structures are selected (MVA eigenvalues ratio > 10. Inclination < 30 deg)
- Same conclusion when only N hemisphere is selected



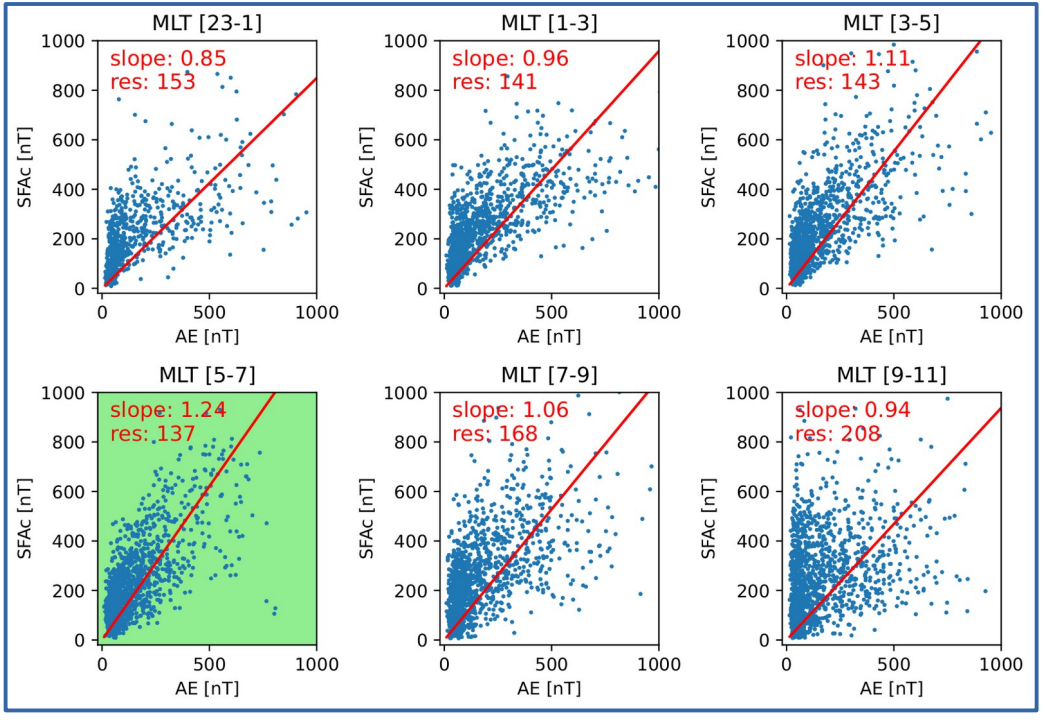
For certain MLT sector the correlation is better

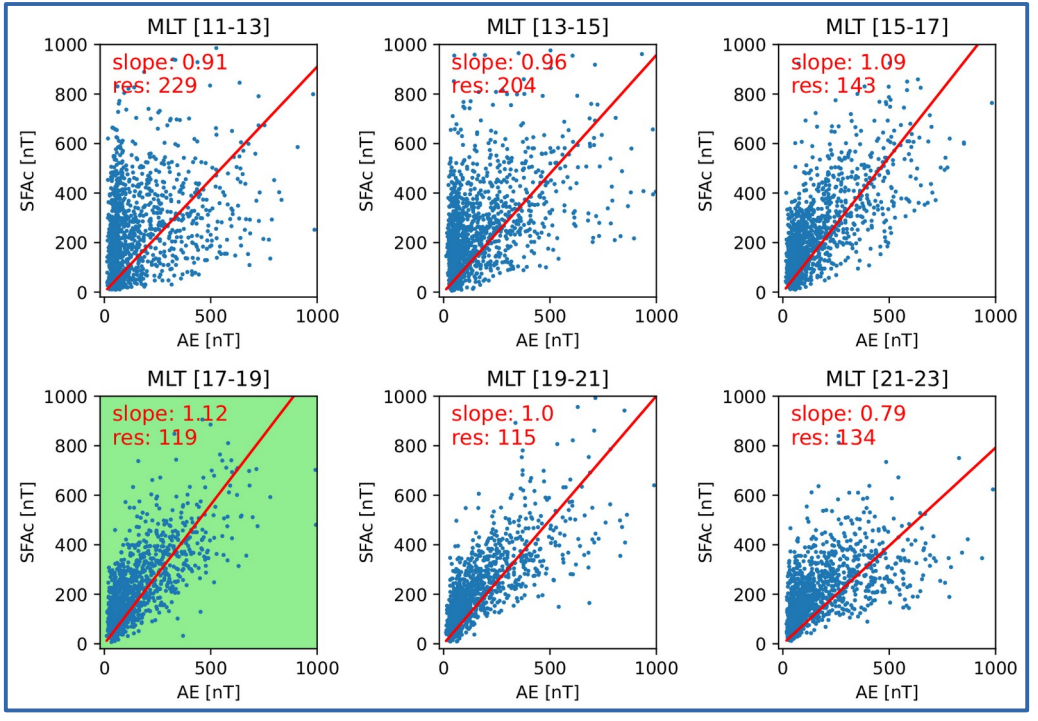
- Time evolution from 28.06 – 19.07 2014
- Swarm orbit in evening – morning MLT

SFAC vs AE comparison

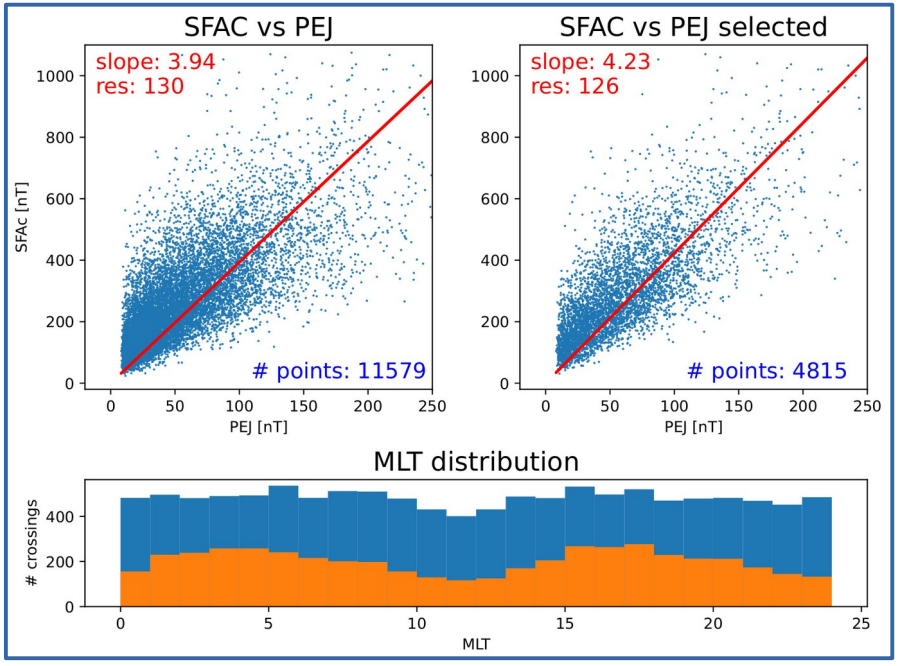
SFAC vs AE comparison on different MLT sectors (2h wide)

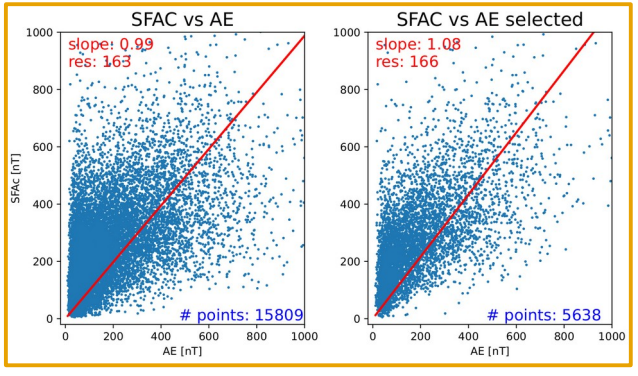
- For the morning – evening sector the correlation is better
- Less good in the noon – midnight sector
- Different character of indices: AE (global) vs SFAC (local)
- Perhaps using AU and AL (instead of AE = AU – AL) would be more meaningful





SFAC vs PEJ comparison





<= SFAC vs AE

Swarm can remotely estimate the polar electrojet:

- Changes in magnetic field intensity or in the dB component along B
- PEJ index (Swarm base) estimates the intensity of the electrojet (line current method, Olsen 1996, Aakjær 2016)
- 4 quantities / orbit

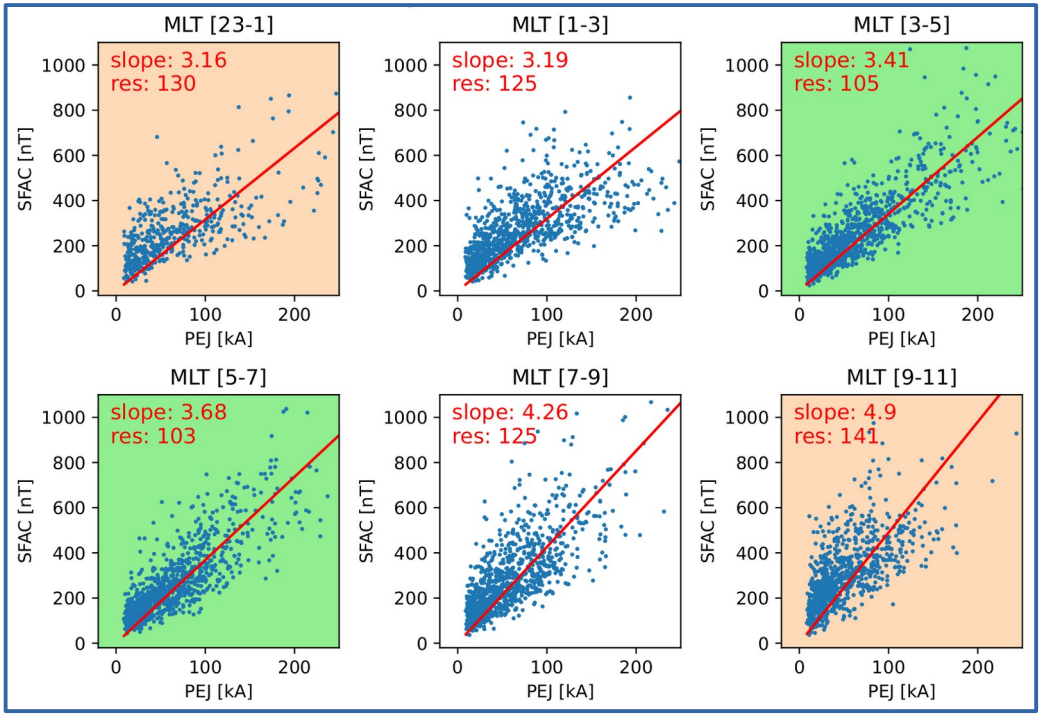
SFAC vs PEJ comparison on all MLT sectors:

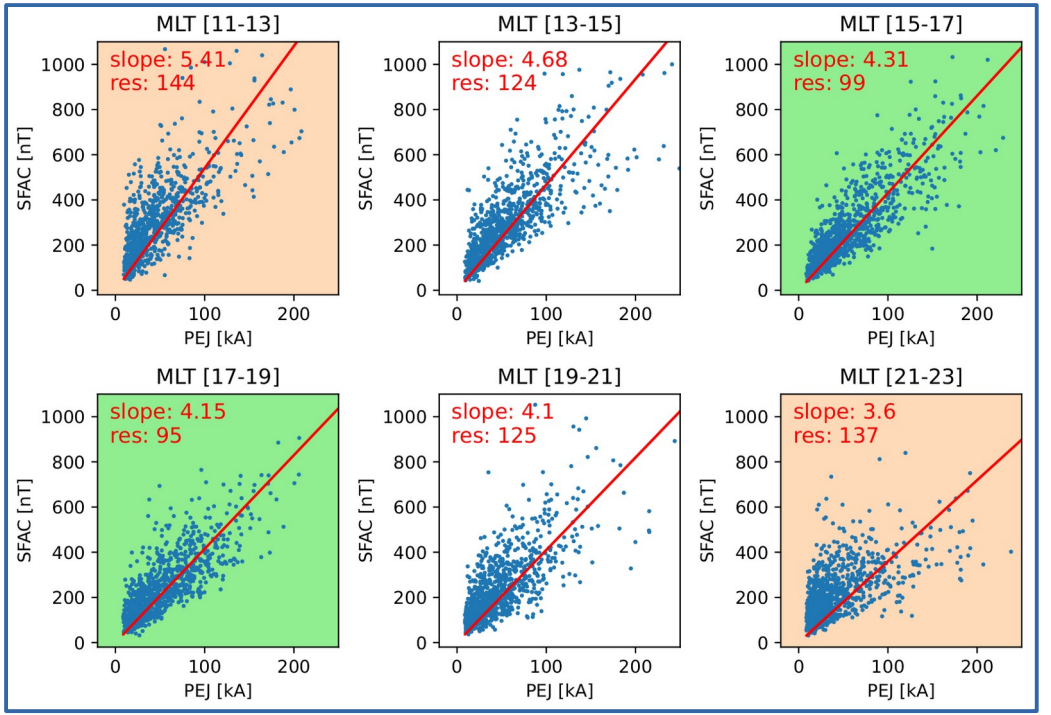
- Left: All points/ all q-orbits. Correlation is better than with AE;
- Around 400 points in each hour of MLT (bottom)
- Right: the correlation slightly improved when planar + well inclined current structures are selected (events in orange in the MLT distribution)
- Both SFAC and PEJ have local relevance

SFAC vs PEJ comparison

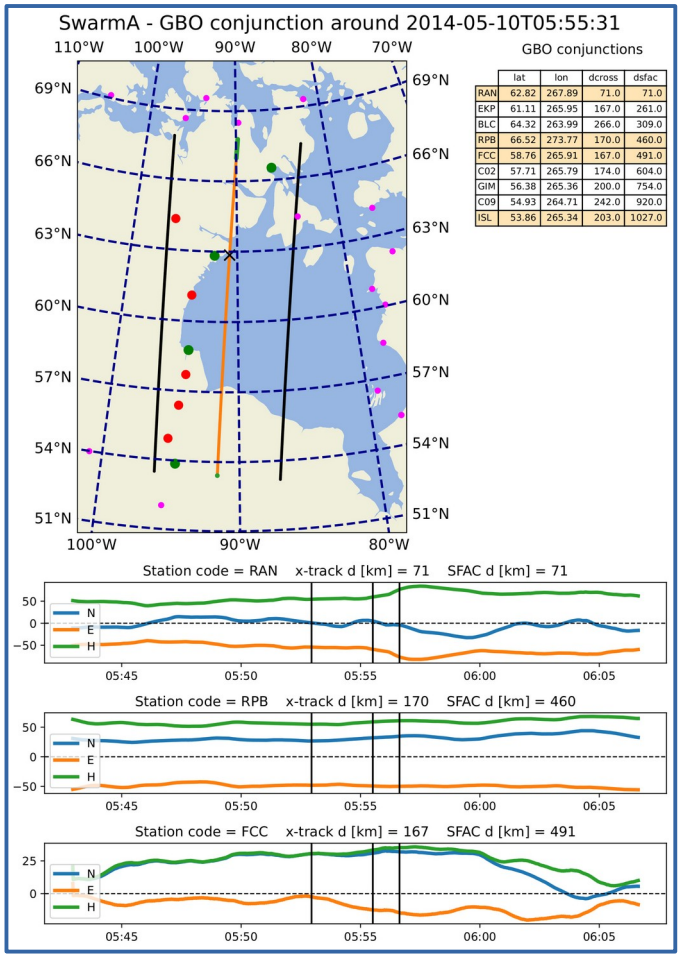
SFAC vs PEL comparison on different MLT sectors (2h wide)

- Relatively good correlation for the morning – evening sectors (green background)
- Correlation at noon (Region 0 FAC) and mid-night (Harang discontinuity) is less good (brown background)
- Here the two dawn/dusk cells meet and the characterization of current with the line current method is less precise





SFAC vs GBO comparison



	lat	lon	dcross	dsfac
RAN	62.82	267.89	71.0	71.0
EKP	61.11	265.95	167.0	261.0
BLC	64.32	263.99	266.0	309.0
RPB	66.52	273.77	170.0	460.0
FCC	58.76	265.91	167.0	491.0
C02	57.71	265.79	174.0	604.0
GIM	56.38	265.36	200.0	754.0
C09	54.93	264.71	242.0	920.0
ISL	53.86	265.34	203.0	1027.0

We used data provided by SuperMAG collaboration

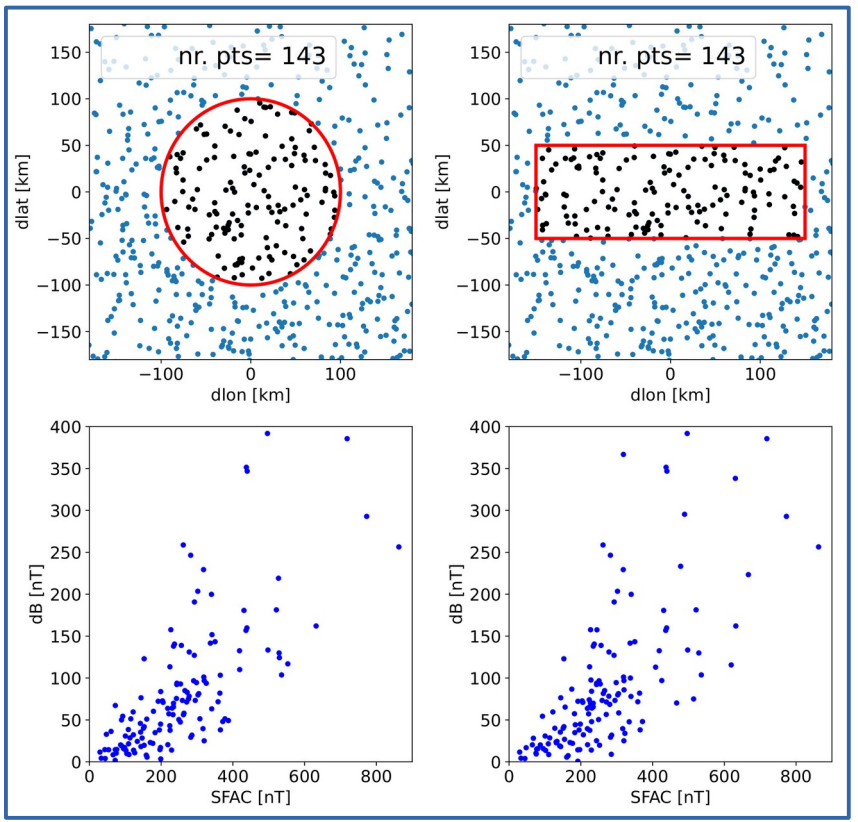
- 1s resolution data (high resolution option)
- Common baseline removal approach

For each quarter orbit:

- The Swarm magnetic footpoint at ground level is computed (orange trace in the generated standard plot)
- Close GBOs when Swarm is within the AO interval are identified
- When data is available (green dots) it is retrieved from SuperMAG
- We were interested in horizontal magnetic component

SFAC vs GBO comparison

SFAC vs dB

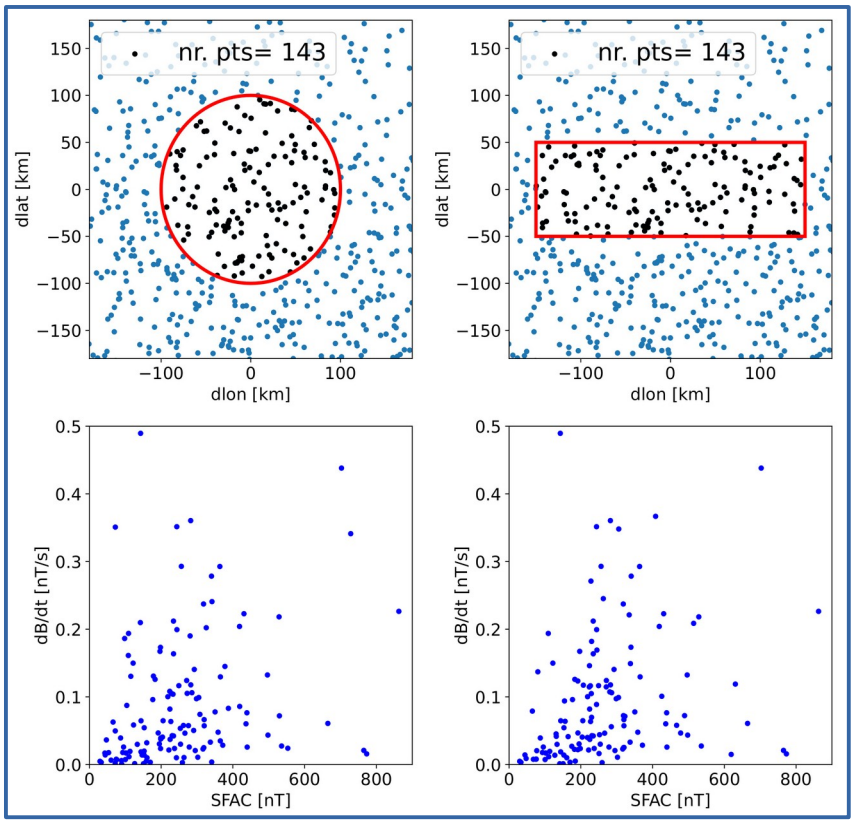


SFAC vs magnetic perturbation at ground

- Upper panels: GBOs position (blue dots) wrt SFAC point (when Swarm recorded the maximum dB)
- Two criteria were used to select “close conjunctions” (black dots), i.e a circle of 50 km radius (left) and a latitude band of 40 x 140 km (right)
- Both selections provide 143 conjunctions (by chance)
- Bottom panels: comparison between SFAC and magnetic perturbation at ground.
- The two quantities are reasonably well correlated

SFAC vs GBO comparison

SFAC vs dB/dt



SFAC vs magnetic perturbation at ground

- Upper panels: GBOs position (blue dots) wrt SFAC point (when Swarm recorded the maximum dB)
- Two criteria were used to select “close conjunctions” (black dots), i.e a circle of 50 km radius (left) and a latitude band of 40 x 140 km (right)
- Both selections provide 143 conjunctions (by chance)
- Bottom panels: comparison between SFAC and magnetic perturbation at ground.
- The two quantities are reasonably well correlated

SFAC vs variation of magnetic perturbation at ground

- dB/dt is more appropriate to quantify GICs intensity
- We used a 20 s interval centered around SFAC time
- Data are more spread
- A detailed analysis should take into account the characteristics of each ground station (e.g. local resistivity)

Conclusions and prospects

SFAC is a simple & easy to implement index

The performance of SFAC index based on 8 month of Swarm data was analyzed statistically

- Better correlation of SFAC with PEJ than with AE, consistent with the importance of the local perspective.
- Better correlation in the morning – evening sectors
- Planarity and E–W alignment of the FACs were less important for improving the correlation.
- Good correlation with dB on ground
- Correlation with dB holds better than with dB/dt (more relevant for SWE)

In the longer run:

- Further development of the SFAC prototype into a full SWE product.
- Extension to LEO satellites, which typically fly at higher altitudes and can only probe FAC system.