Field-aligned current ordering in ground and space measurements

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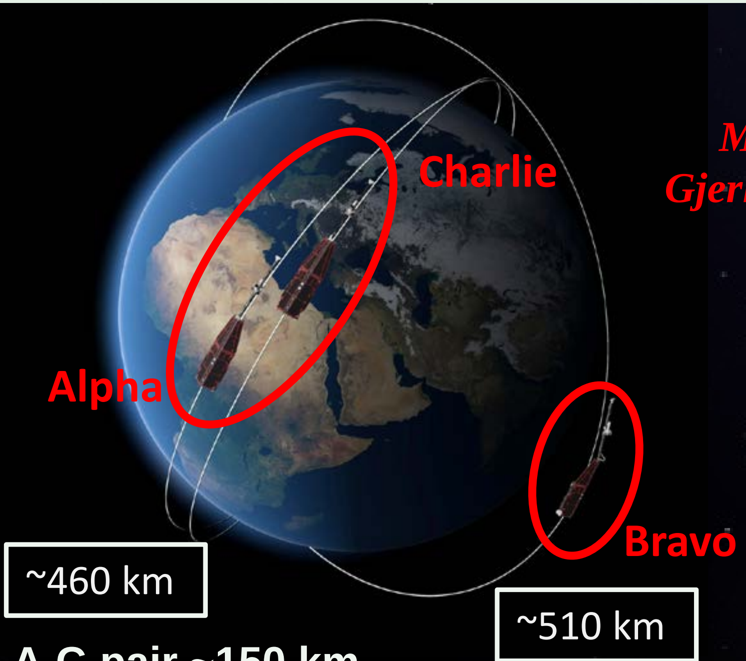

A-C pair ~150 km.

B relative drifting LT.

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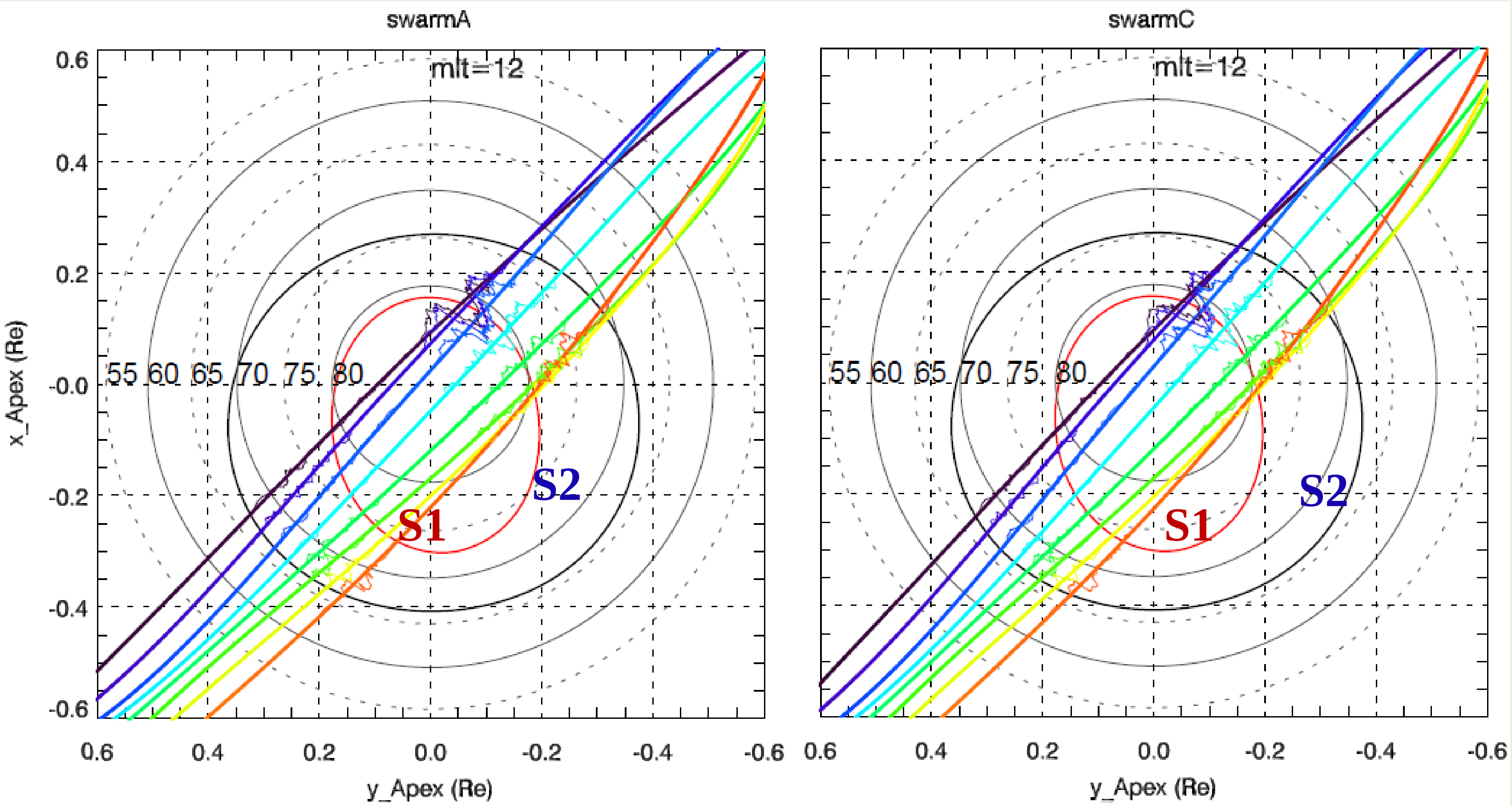
FAC correlation study: probing the temporal and MLT dependence

- **Correlations between A-C orbits**: FACs are given along Swarm orbits for A (left) and C (right)
- Similar signatures can be seen close to **model auroral boundaries** (as guide only)
- In principle, the A-B and C-B pairs can be used when the Swarm B lies close to A-C

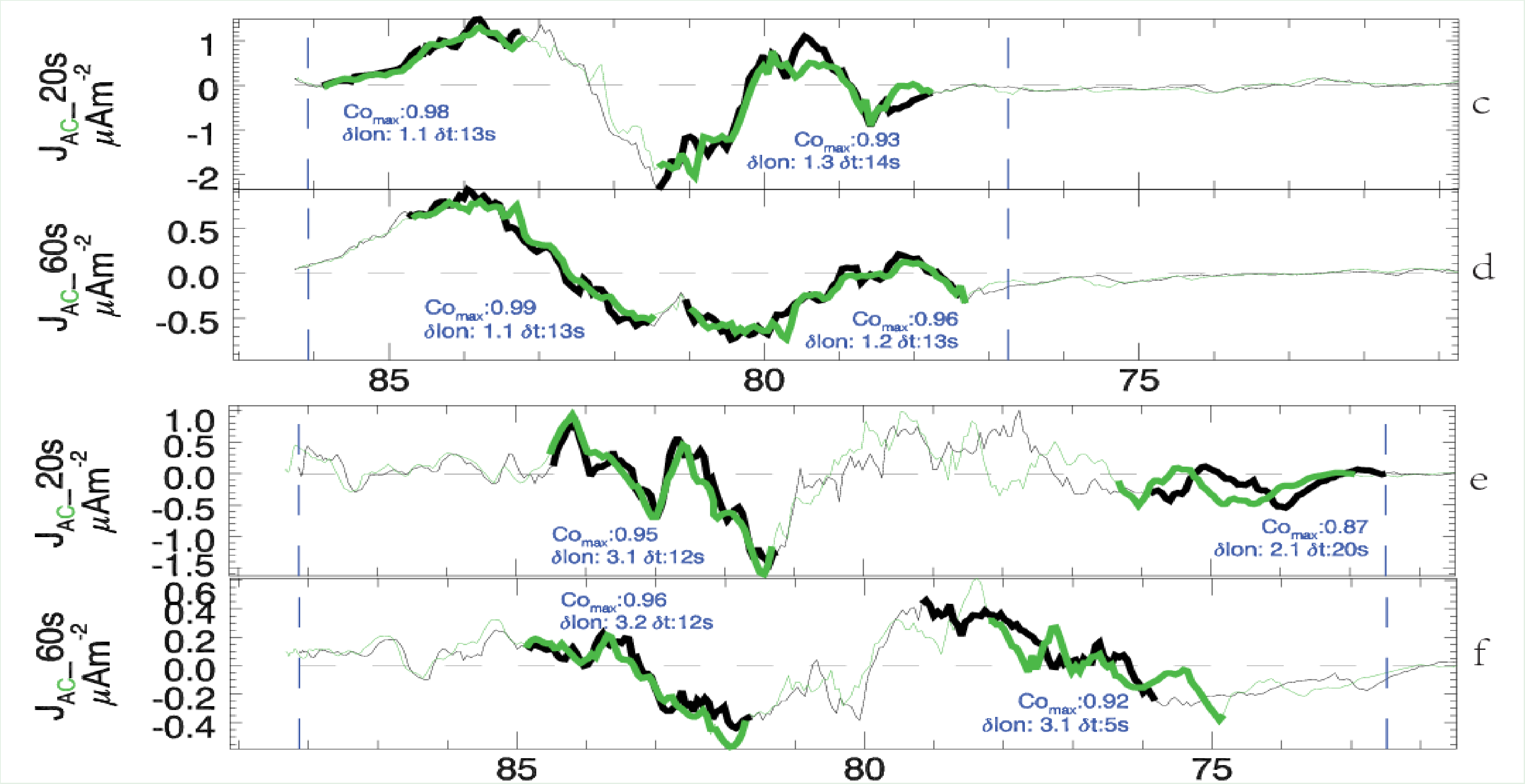
- Maximum cross-correlations (from sliding segments) are found in terms of:
  the required time shift *dt* (A-C) and corresponding d(long)
- S1 and S2 ovals are best-fitted, auroral boundaries from the method of *Xiong et al.* (see later)



FAC correlation study: probing the temporal and MLT dependence

- **Sensitivity to the low-pass filtering level**: essentially selects the scale of the FACs arises from differences between signals at A and C: problem of temporal/spatial mixing
- Examples are plotted in terms of APEX latitude

- S1, S2 positions for **each pass provide actual positions** of max FAC intensity gradient
- Define broad region 1 (R1) and region 2 (R2) intervals

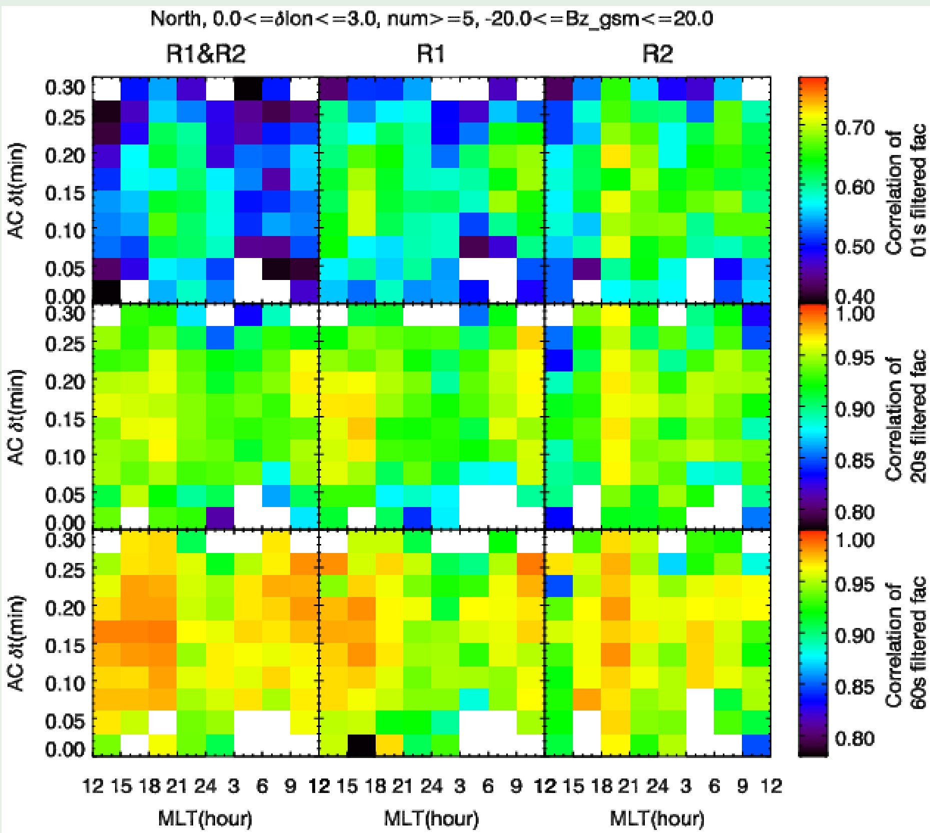


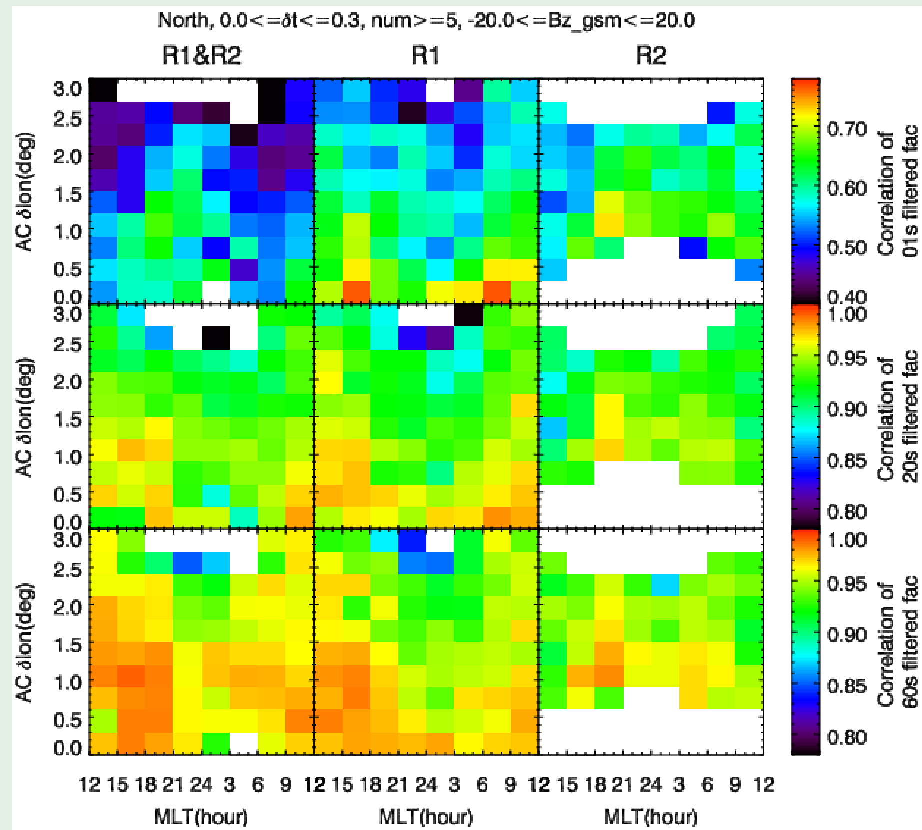
FAC correlation study: probing the temporal and MLT dependence

- Results show R1 and R2 each have **MLT trends** which are consistent with typical behaviour
- Seen for both the *dt* and the *d(long)* correlation trends; computed as a function of MLT

Statistically:

- R2 shows broad MLT distribution of higher correlations with min near noon
- R1 shows higher correlations near noon and post noon, localised in dt



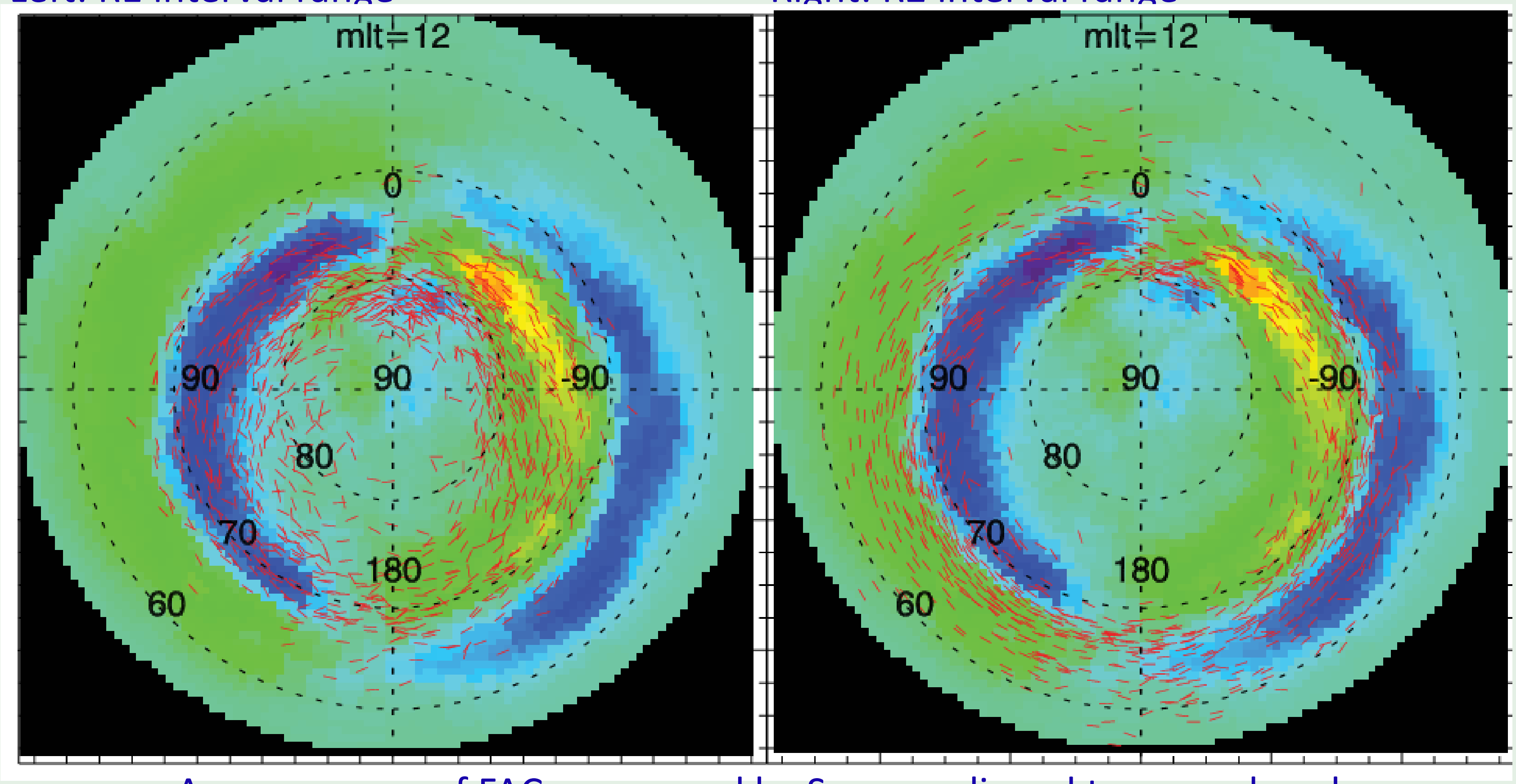


FAC correlation study: current sheet alignments (20 sec filtered data)

- **Orientations from connecting line** between sliding interval mid-points on A-C orbits (at position of maximum correlation) ***Yang, Dunlop, et al. (2018)***
- Highest (large scale) ordering on dusk-side R2; higher variability in R1 (quiet time climatology)

- Expect **smaller-scale variations for high (storm) activity**.
- **Single passes can be tied to prevailing conditions and particular form of S1, S2 boundaries**

Left: R1 interval range   Right: R2 interval range



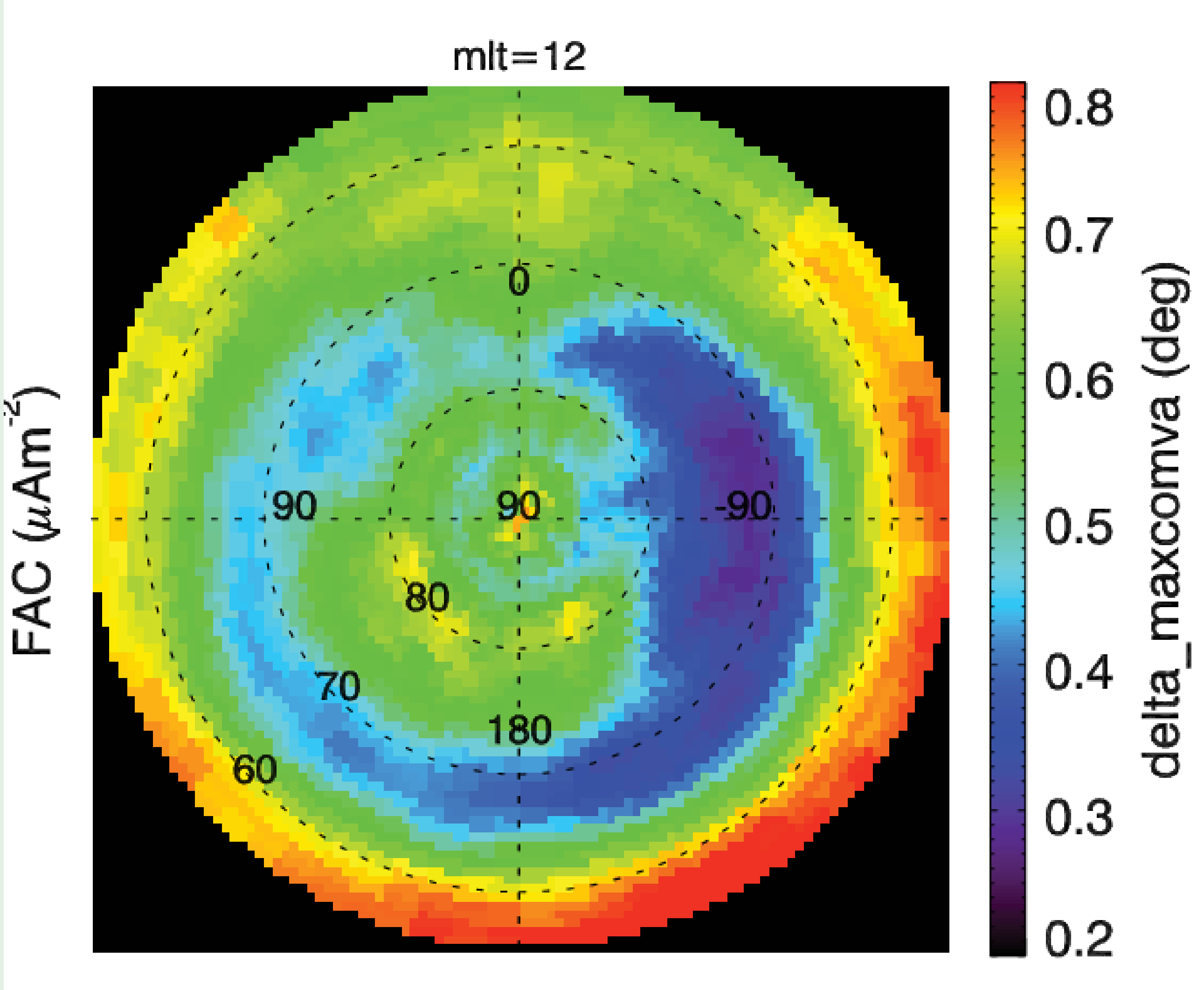
Average maps of FACs measured by Swarm: aligned to auroral oval.

Comparison to maximum variance (from MVAB): (20 sec filtered data)

Recomputed current sheet alignments from maximum variance in magnetic residuals (at A&C)

Closest agreement for most intense currents.

- Plot shows the intersection angle of current sheet orientations calculated by both maximum correlation and MVA method
- Swarm A and C data used for MVA
- Note the very low values (very good agreement between the methods) in the regions between R1/R2.
- All deviations are less than a degree.



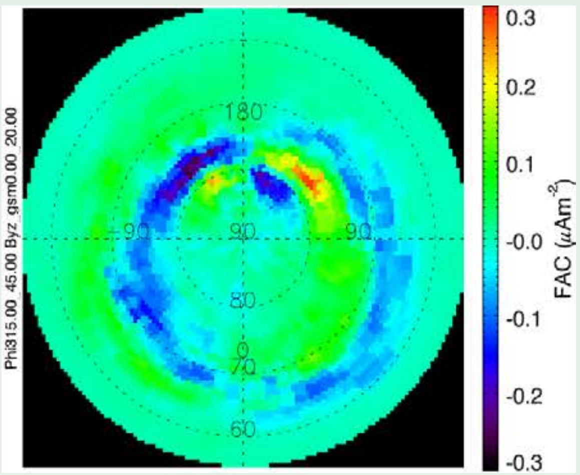
Current sheet orientations on a polar grid (right panels)

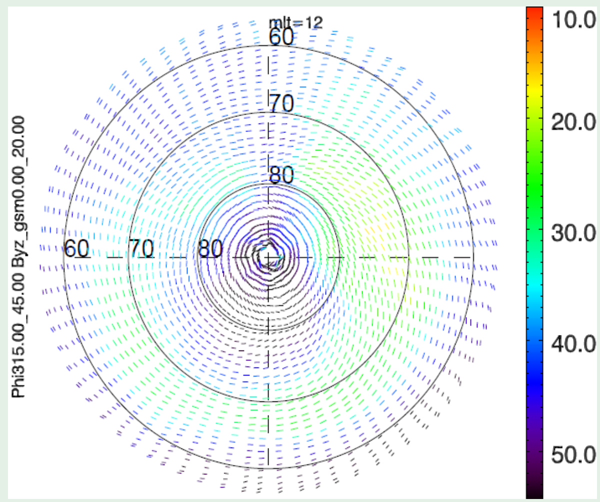
Orientations from maximum variance analysis (middle panels)

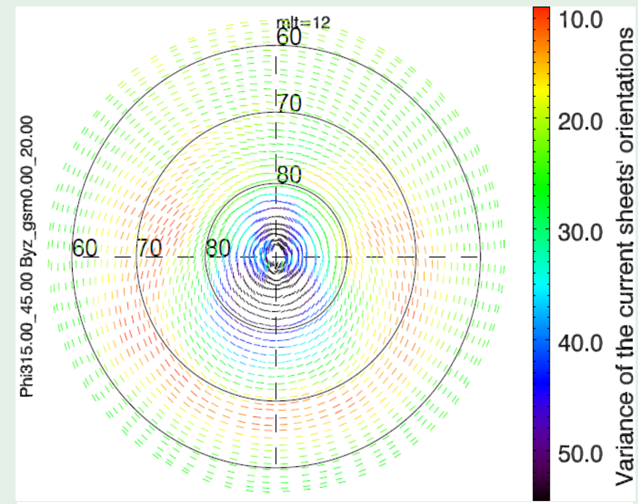
Variance (stability) of the orientations in each Lat/MLT bin (red – stable; blue - unstable)

Strongest ordering lies around R2 zone, dawn-dusk

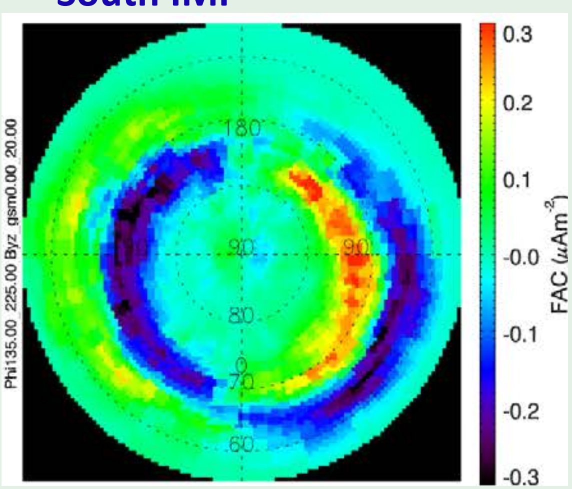
North IMF

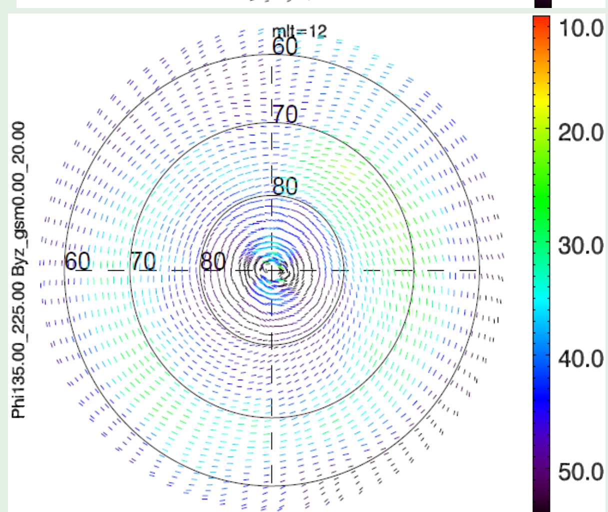


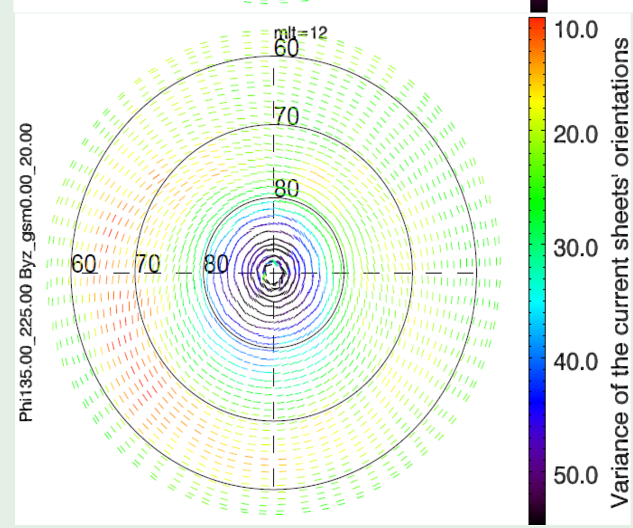




South IMF





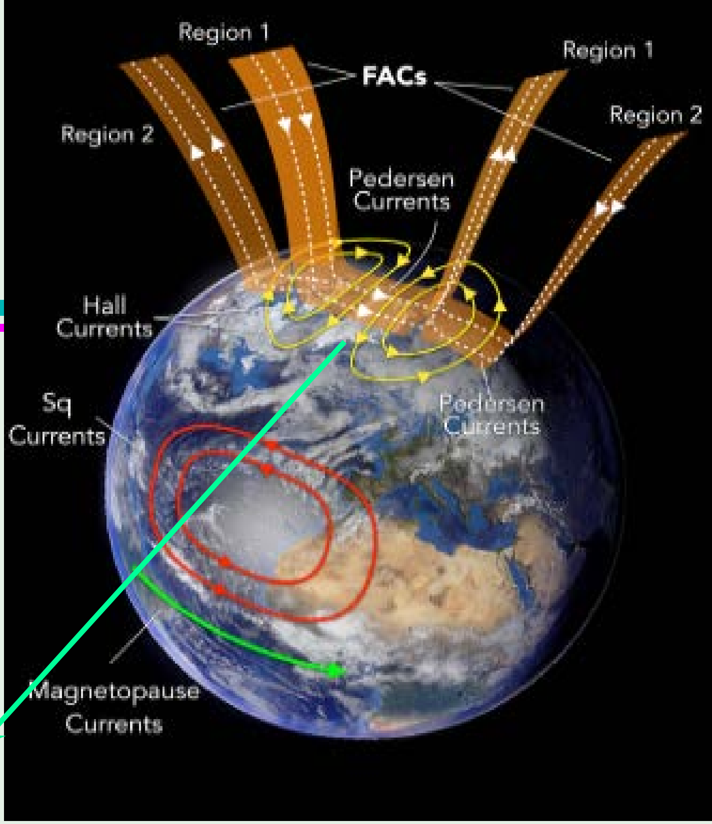


Determination of auroral boundaries:

Combine with FAC orientations: pass by pass

Based on positions of maximum-gradient of FAC intensity:

defined as S1 and S2 for Region 1 and Region 2 zones

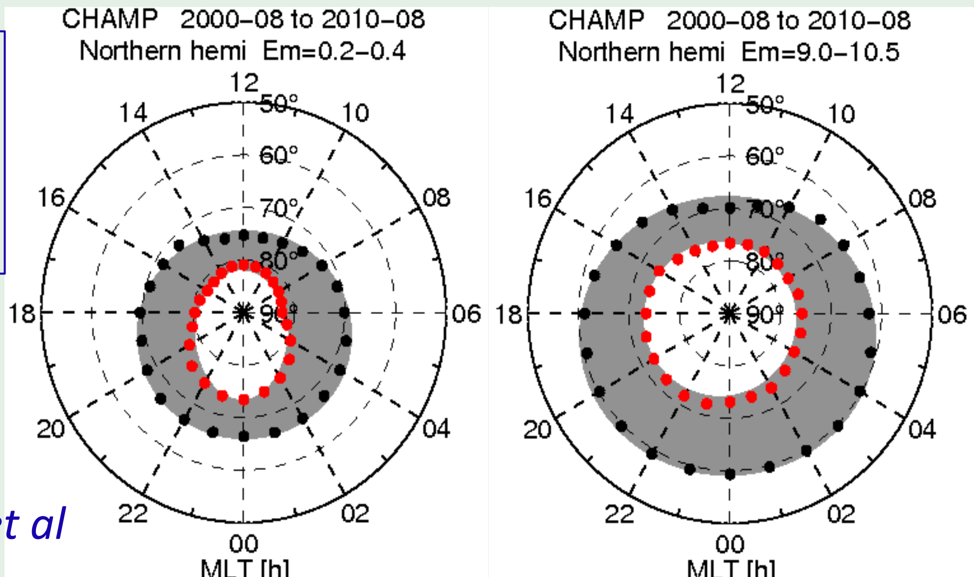


Procedure definition:

Semi-empirical form of the S1 and S2 boundary ovals from statistical analysis of CHAMP data (+ model extension to Swarm data) - *(Xiong et al., 2014a,b)*

Elliptical shape depends on the solar wind merging electric field (E_m) *(Newell et al, 2007)*

Ellipse fit
(x_0, y_0)
φ_0
$Semi_x$
$Semi_y$



Low Activity **High activity**

After *Xiong et al*

Statistical model of auroral oval: parameterization by solar wind merging electric field (Em)

$$E_m' = \frac{1}{3000} V_{SW}^{\frac{4}{3}} \left(\sqrt{B_y^2 + B_z^2} \right)^{\frac{2}{3}} \sin^{\frac{8}{3}}\left(\frac{\theta}{2}\right)$$

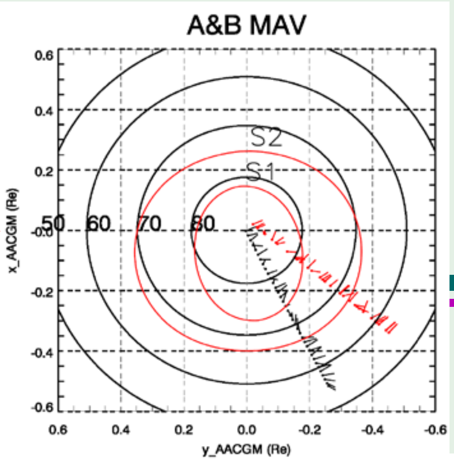
Possibility of NRT values based on Em and actual Swarm FAC’s

Model can be compared to actual positions of S1, S2 pass by pass

Similar to empirical model determined from 10 years of CHAMP observations

Development of combined techniques: I

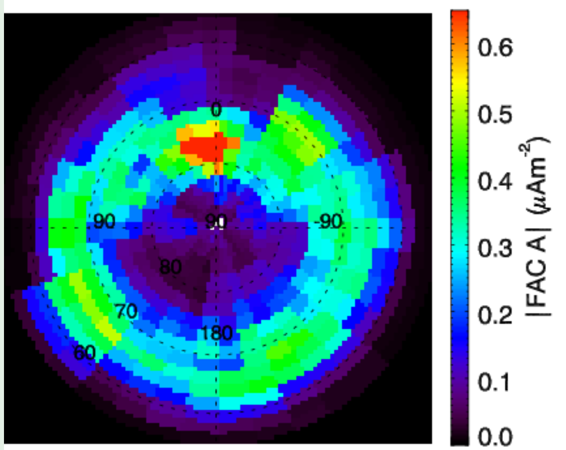
Three methodologies link: auroral boundaries;
FAC sheet orientations and intensity gradients,
and GIC ground signals (*dH/dt*)



1. Current sheet orientations; relative to (sub-) **auroral S1/S2** boundaries (choice of time filtering)

[Combination of semi-empirical model with actual positions of the maximum FAC intensity gradients pass by pass provided a predictor corrector method]

Swarm FAC

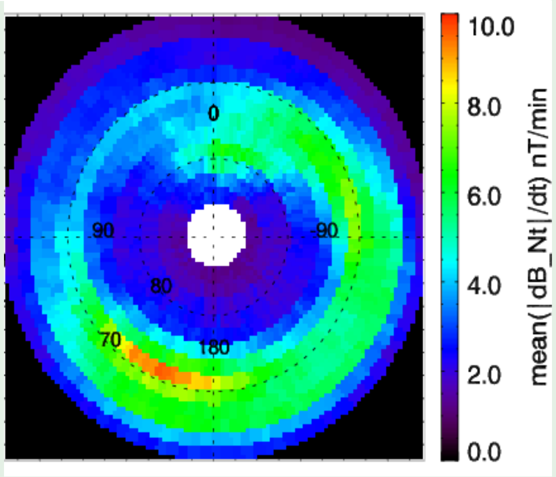


2. Coordination with ground signals: explores the influence of external currents on ground signals

(comparison: Swarm and ground magnetometers)

[Proxi: Rate of change of horizontal magnetic component (*dH/dt*) is proxy for GICs]

Ground |*dH/dt*|



Right: (APEX coordinates)
Distribution of FACs from Swarm (top) and *dH/dt* (bottom) from SuperMAG for sub-storm recovery phase.
Shows similarities: main differences in pre-midnight MLT sector.

Similar results for storm time conditions and main phase intervals

Development of combined techniques: II

Three methodologies link: auroral boundaries;

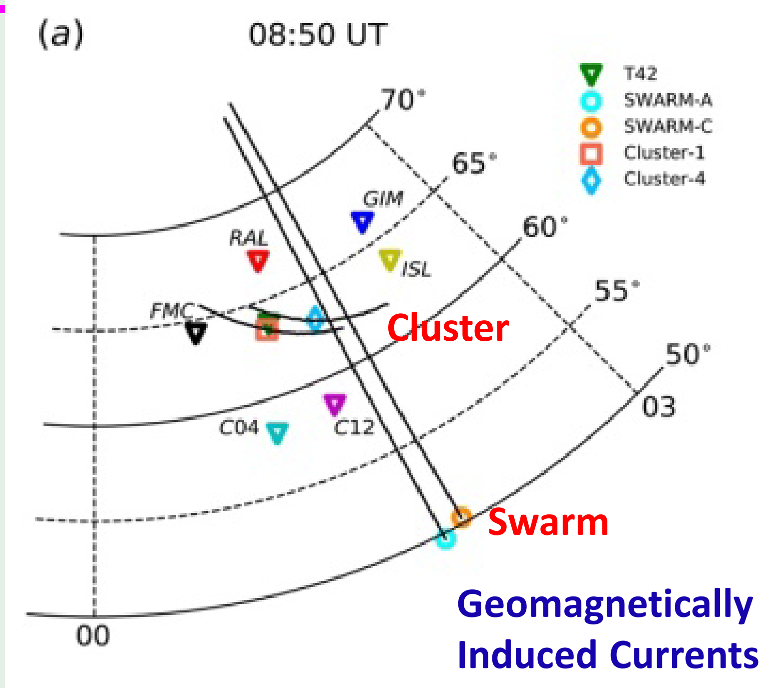
FAC sheet orientations and intensity gradients, and GIC ground signals (*dH/dt*)

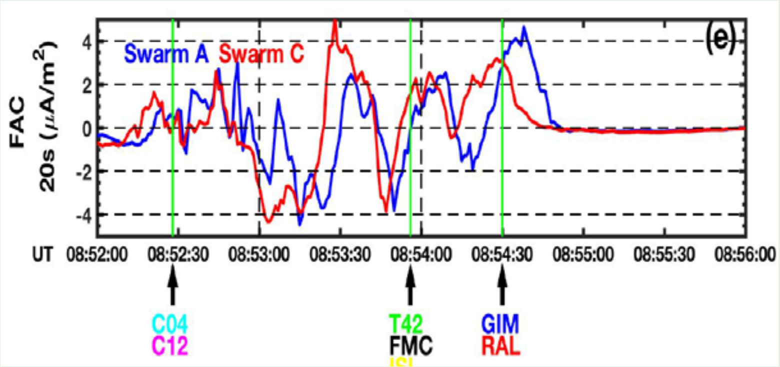
3. Individual events : behaviour of ionospheric and ground currents during solar storms and geomagnetic sub-storms

[**FAC scaling**: similar signatures from Cluster to Swarm mapped to model currents (e.g. from AMPERE)]

Right: (poster: *Wei et al*. ST2.5)
Cluster-Swarm-SuperMAG conjunction
(in location and timing):

- sub-storm driven BBF - Cluster and Swarm both see onsets of FACs (consistent with a SCW structure, modified by added R2 FAC)
- SuperMAG ground stations see, developing signatures across Swarm and Cluster footprints (consistent with the presence of a FAC sheet in the centre of the group of stations)





Summary:

- Estimate of current sheet orientations using dual spacecraft, with associated correlation and geomagnetic activity; with recent time history of previous orbits (compare with S1, S2 positions)
- Use of predicted model estimates of the auroral boundaries (S1,S2) from prevailing upstream merging electric field, E_m; verification from pass by pass estimates of FAC gradients
- Verification of stability against single-spacecraft maximum variance estimates
- Direct coordination to ground signatures of (vector) dH/dt from clusters of ground magnetometers near swarm footprints (feasibility demonstrated)
- Complementary statistical maps, binned to a variety of SW and geomagnetic parameters
- Demonstration of individual event analysis coordinating ground and space signals: BBF driven event (see poster: *Wei et al*. ST2.5).