Determination of Field-Aligned Currents Using the Dual-Spacecraft Approach in the Swarm Constellation Mission

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Dual Ionospheric Radial Current (IRC) and Field-Aligned Current (FAC) Estimations

The lower pair of the **Swarm satellite constellation** offers a unique opportunity to determine both radial and field-aligned currents. The horizontal **B** field components measured by the **Swarm A and C** satellites at **four measurement points**, which form a symmetric quad are used to estimate the radial current density.

Ampère's law in integral form is used in the case of multiple data points:

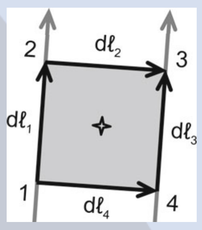
$$j = \frac{1}{\mu_0 A} \oint \vec{B} \cdot d\vec{\ell}$$

Here, the discrete form is applied to solve the ring integral:

$$j_{IRC} = \frac{1}{\mu_0 A}\left[\left(B_x^{t_1} + B_x^{t_2}\right)dl_1 + \left(B_y^{t_2} + B_y^{t_3}\right)dl_2 - \left(B_x^{t_3} + B_x^{t_4}\right)dl_3 - \left(B_y^{t_4} + B_y^{t_1}\right)dl_4\right]$$

Where μ_0 is the vacuum magnetic permeability and A is the integration area

$$A = \frac{1}{2}\left(dl_1 + dl_3\right)\left(dl_2 + dl_4\right)$$



Along-track variation, B_x, is derived from the two subsequent measurements: Δt = 5s corresponding to dl_1 (dl_3) = 38 km.

Cross-track separation: 1.4º in longitude corresponding to dl_2 (dl_4) = 50 km at 70º latitude.

The field-aligned current (**FAC**) is obtained from the ionospheric radial current (**IRC**) projection on the field direction

$$j_{FAC} = -\frac{j_{IRC}}{\sin I}\left[\frac{\mu A}{m^2}\right]$$

where ***I* is the magnetic field inclination**. IRCs and FACs are derived from the **low-pass filtered** residual B-field data to account for the lateral distance of the satellites (only currents with **spatial scale lengths > 150 km** are represented). A 3-dB cut-off period of 20 seconds is used (7 seconds filter length) for filtering.

Calculations near the equator and poles

- **FACs** are not estimated near the magnetic equator for $|I| < 30º$
- **FACs and IRCs** are not estimated near the poles for latitudes > 86º.

Upward and downward current directions

Northern Hemisphere

- Upward: +IRC and −FAC
- Downward: −IRC and +FAC

Southern Hemisphere

- Upward: +IRC and +FAC
- Downward: −IRC and −FAC

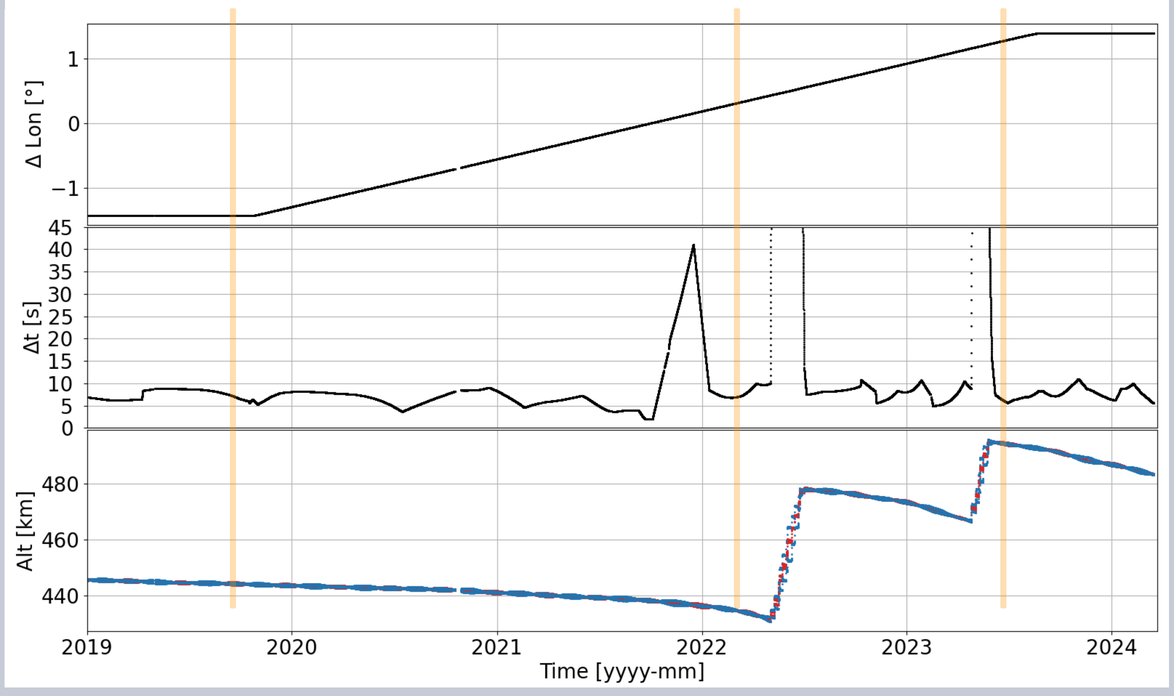
Dual FAC (IRC) Algorithm Updates Necessity Due to Swarm Orbit Evolutions

The **Swarm L2 dual FAC** data product (FAC_TMS_2F) has been impacted by incorrect values **due to changes in the orbits of Swarm A and C** satellites (described below). An **update to the dual FAC algorithm** will eliminate these incorrect values and **improve the accuracy** of current density estimates.

Swarm A and C constellation and orbit evolution

- The mission was **launched** on 22 **November 2013**
- The **initial constellation** of the mission was achieved on 17 **April 2014** with **1.4º longitudinal separation** at the equator between **Swarm A and C**
- The manoeuvre that slowly **reduced the separation in longitude** between **Swarm A and C** started in **October 2019** and reached the **counter-rotation** phase in **October 2021**
- **Orbit raise** campaign of **Swarm A and C** started in **May 2022**
- As of **August 2023**, the longitudinal separation at the equator between **Swarm A and C is -1.4º** again

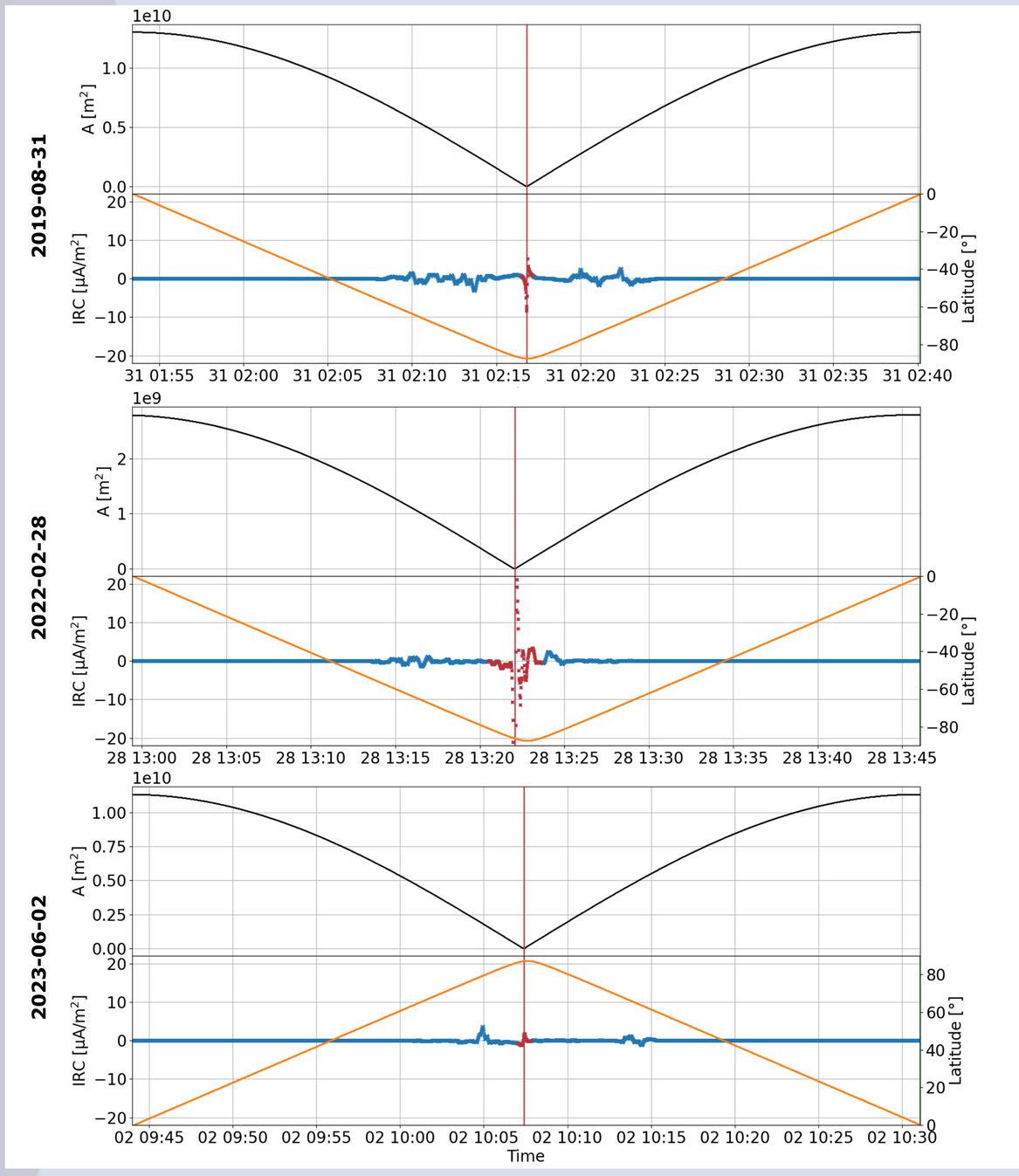
The equatorial distance and along-track time difference developments between Swarm A and C from 2019-01-01 to 2024-03-15



Dual FAC (IRC) algorithm changes

The following is a **set of parameters** that will control the **automated** daily **processing and production** of CDF data files. The **limit parameters** for the integration area and **time separation** determine the time interval that will be **ignored** during the Dual FAC **processing and reprocessing**.

Time threshold	Along-track time difference between two satellites. If this threshold is reached. **No daily CDF file** will be created	11 seconds
Upper area threshold	Upper integration area limit, maximum value per half orbit, for producing daily files. If this threshold is reached. **No daily CDF file** will be created	1.25e9 m^2
Lower area threshold	Lower integration area threshold for latitudes when **IRC is set to NaN** while integration area becomes too small	3.00e8 m^2



In the updated version, the **lower area threshold** is used **instead of** restricting through **86º for FACs and IRCs** near the poles.