

The *Swarm* constellation mission: upper atmosphere parameters and high precision magnetic field

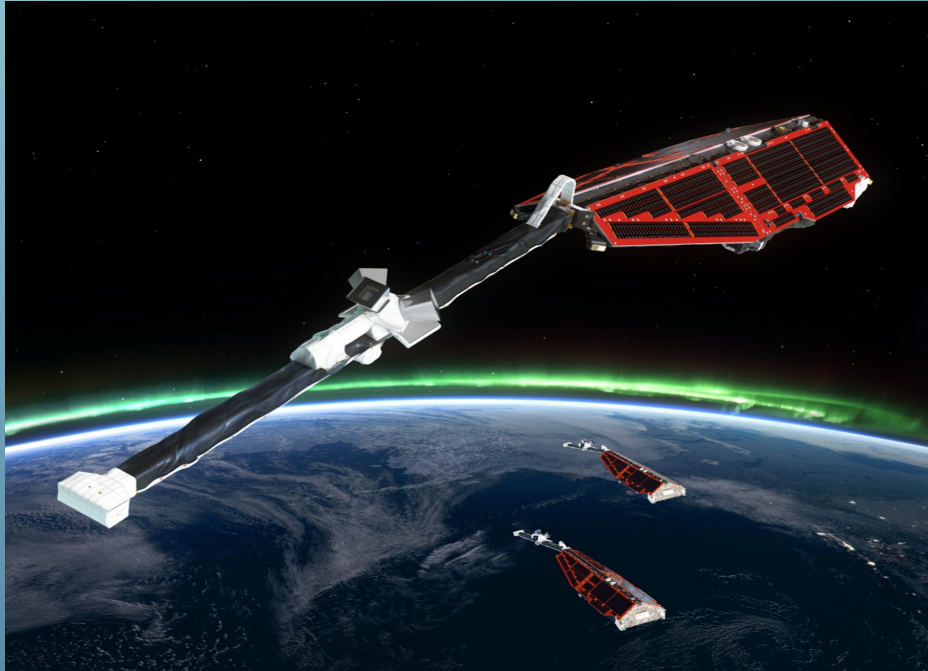
Claudia Stolle^(1,2)

& Swarm Science Team

⁽¹⁾GFZ Potsdam ⁽²⁾University of Potsdam



Swarm constellation mission



Mission and Constellation

- Earth Explorer Mission of the European Space Agency (ESA)
- Launched 22 November 2013
- Operation 5+ years

Satellite A + C:

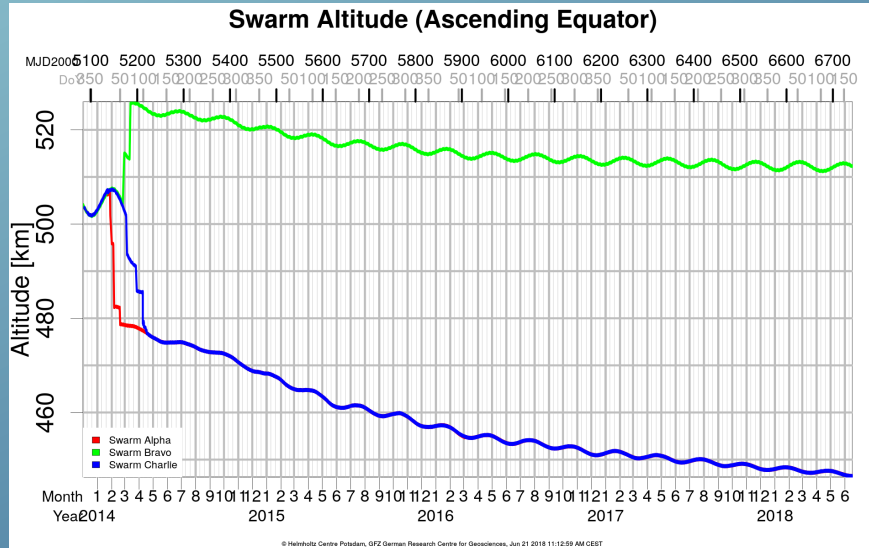
- Altitude 448km
- Side-by-side flying (Δlon : 1.4° , ΔLT : 6 min, 160km distance (at equator))
- Longitudinal difference $\Delta t=7\text{-}13\text{s}$, Δlat : 56-104km

Satellite B:

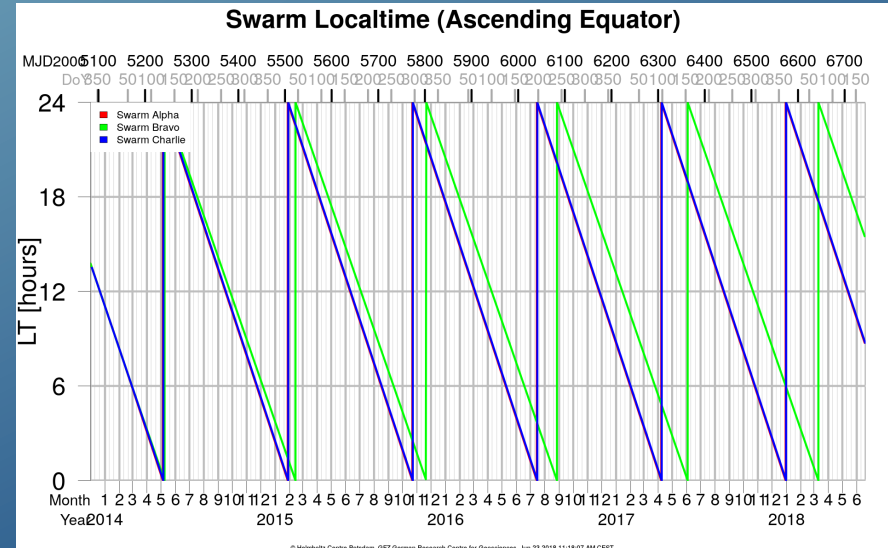
- Altitude 512km

Swarm constellation mission

Orbit altitude



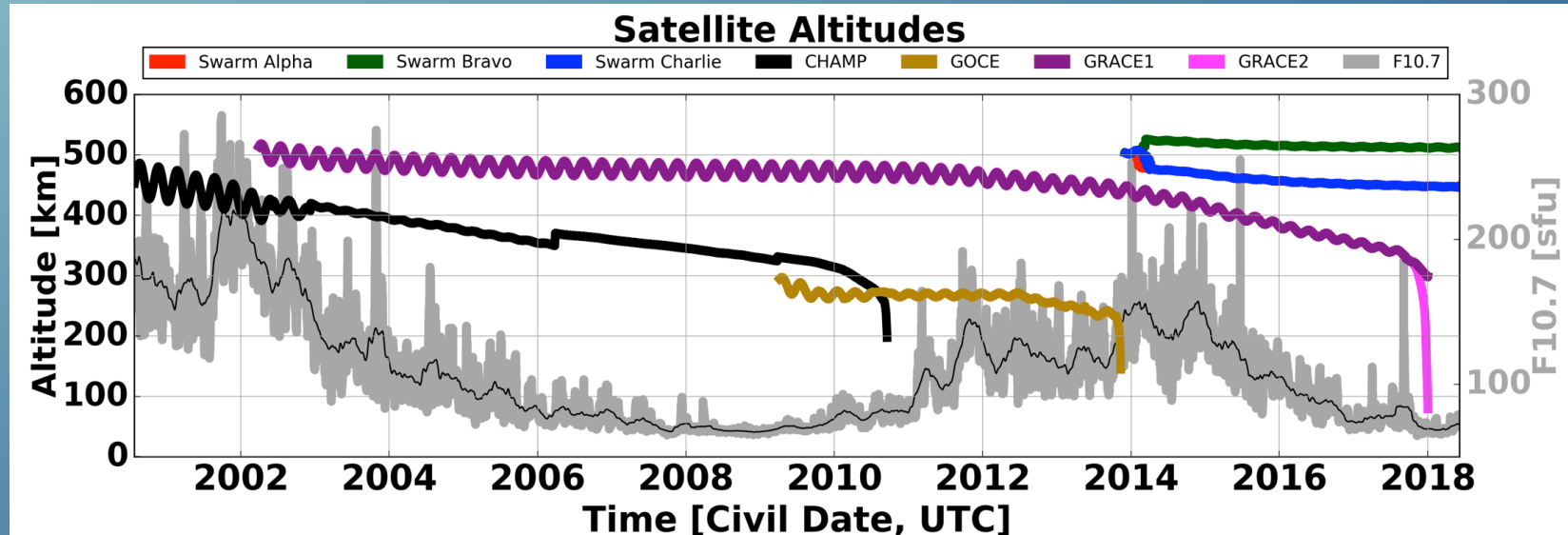
Local time



> movie

Long-term observations from polar orbiting LEO satellites

- Coverage: Global, local time fix or slowly processing, 250-550 km altitude
- Multiple event studies
- Regular and periodic processes, climatology



Swarm payload

Flight direction



Star tracker

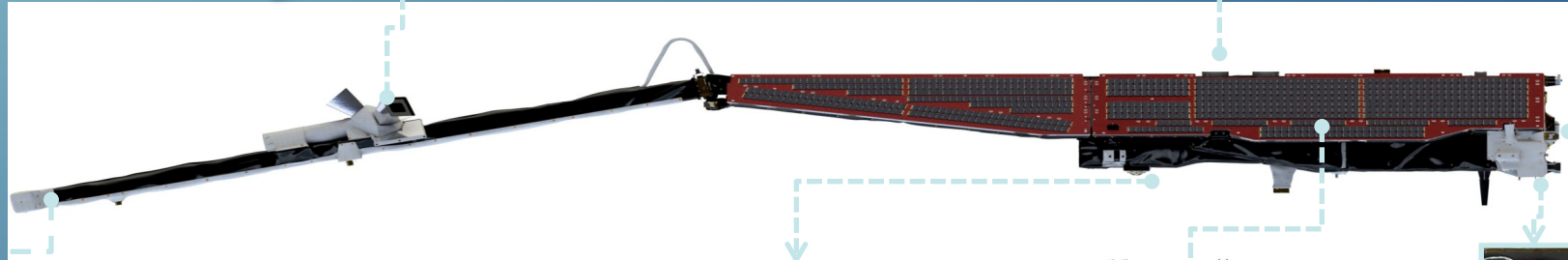
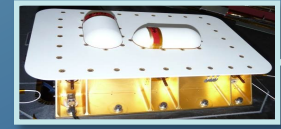


Vector magnetometer

GPS receiver



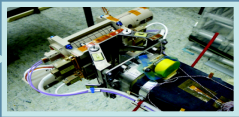
3D-ion imager



Laser reflector



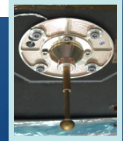
Absolute scalar magnetometer



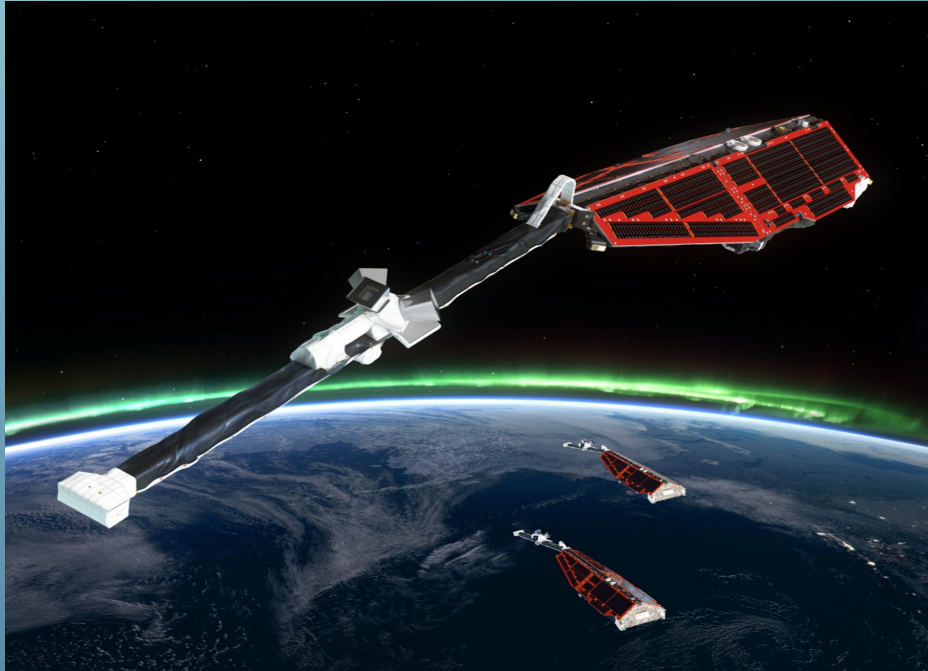
Accelerometer



Langmuir probe



Swarm data products



Calibrated time series; derived products

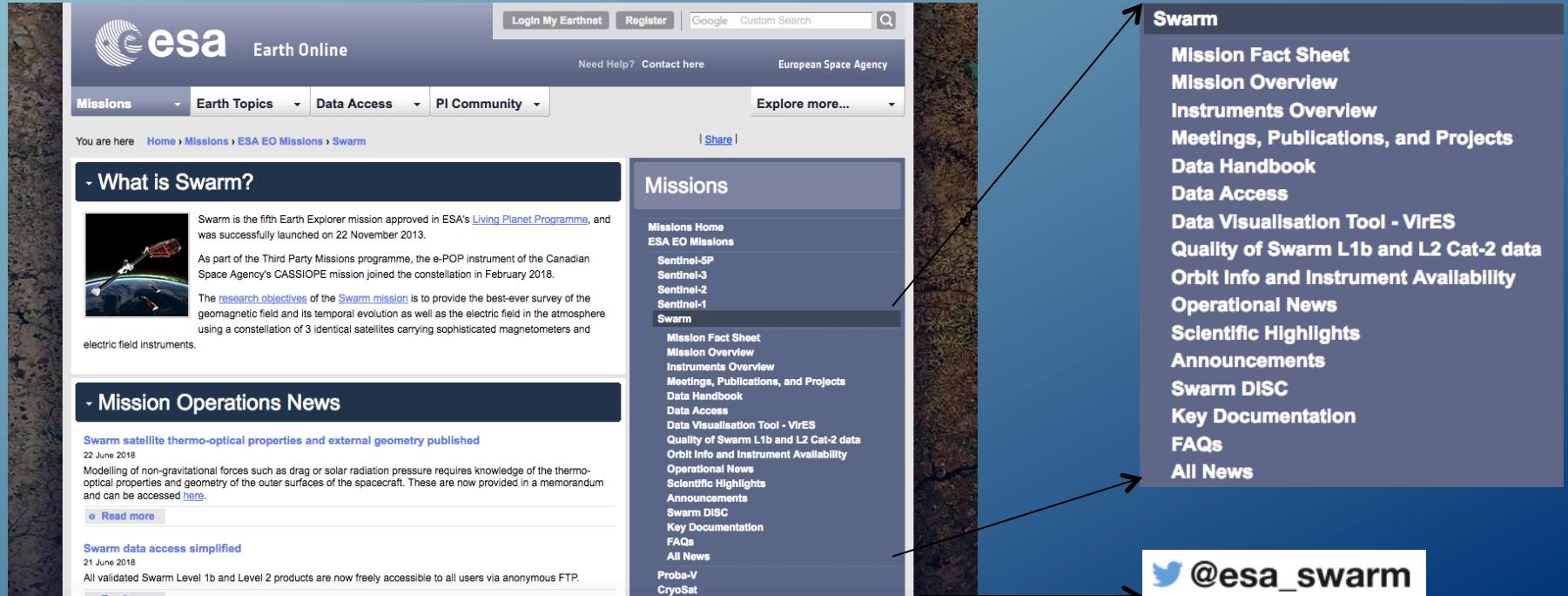
- High-precision magnetic field (1Hz, 50Hz)
- Attitude, Orbit, GPS RINEX (1Hz)
- Electron and ion density and temperature, ion drift velocity, electric field (2Hz)
- Radial and field-aligned currents (1Hz)
- Equatorial "bubble" index (plasma irregularities, 1 Hz)
- Dayside equatorial eastward electric field, EEJ (orbit)
- Total Electron Content (1Hz)
- Thermospheric density
- Main magnetic field models

Swarm information and data

earth.esa.int/swarm

swarm_feedback@esa.int


twitter.com/esa_swarm



The screenshot shows the ESA Earth Online website for the Swarm mission. The main content area includes a 'What is Swarm?' section with an image of the satellites and text describing the mission's goals and instruments. Below this is a 'Mission Operations News' section with two articles from June 2018. A 'Missions' sidebar on the right lists various resources. An overlay on the right side of the image contains a 'Swarm' menu with links to all these resources. Arrows point from the menu items to their corresponding locations on the website. At the bottom right, a Twitter handle '@esa_swarm' is displayed with an arrow pointing to the social media link at the top right of the slide.

Swarm

- Mission Fact Sheet
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- Quality of Swarm L1b and L2 Cat-2 data
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 @esa_swarm

Swarm radial and field-aligned currents (FAC)

- Derived from magnetic field time series
- Radial currents** from Ampère's law $j = \frac{1}{\mu_0 A} \oint \vec{B} \cdot d\vec{\ell}$ in its discrete form

Option 1: Single-satellite approach (*Swarm* A, B, C, 1Hz)

- Variations of $\Delta \mathbf{B}$ in east-west direction neglected

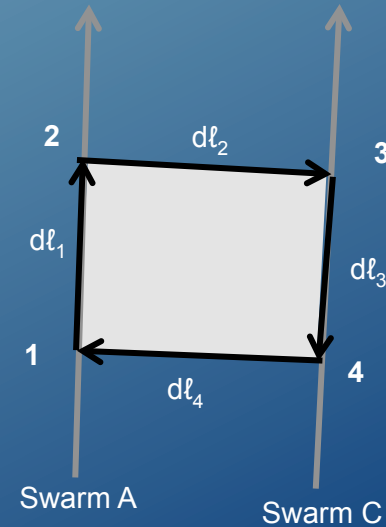
Option 2: Dual-satellite approach (*Swarm* A, C, 1Hz – 20s filt)

- Variations of $\Delta \mathbf{B}$ from discrete square \rightarrow

FAC are obtained

from projection of radial currents on the field direction

$$j_{FAC} = -\frac{j_{IRC}}{\sin I} \left[\frac{\mu A}{m^2} \right], \text{ where } I \text{ is magnetic field inclination}$$



<https://earth.esa.int/web/guest/missions/esa-eo-missions/swarm/activities/conferences/swarm-ionospheric-currents>

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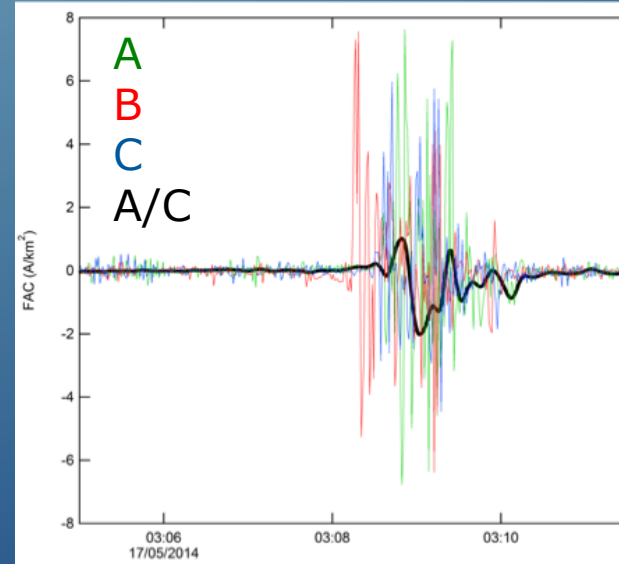
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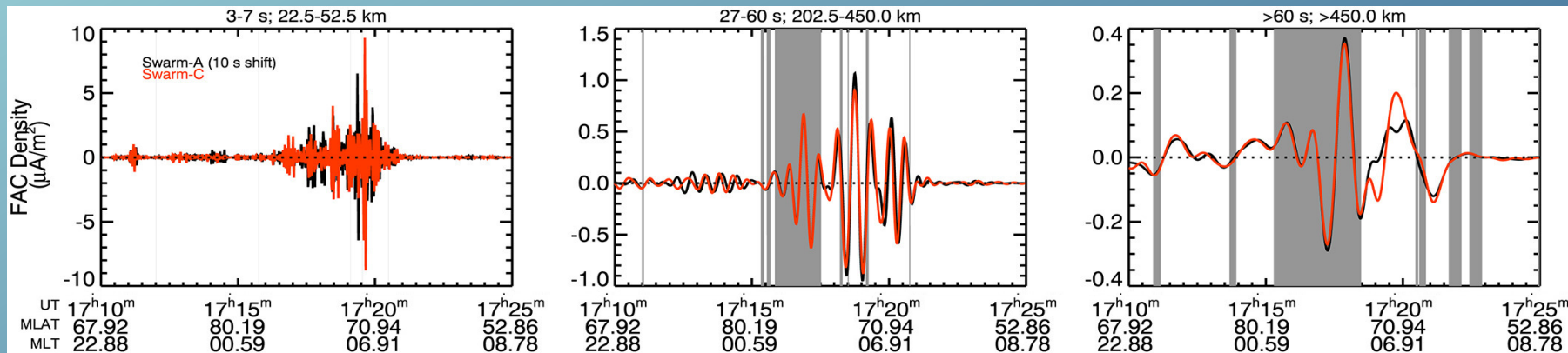
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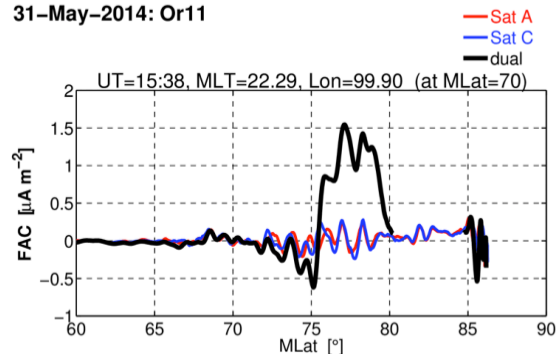
<https://earth.esa.int/web/guest/missions/esa-eo-missions/swarm/activities/conferences/swarm-ionospheric-currents>

Swarm field-aligned currents (FAC)

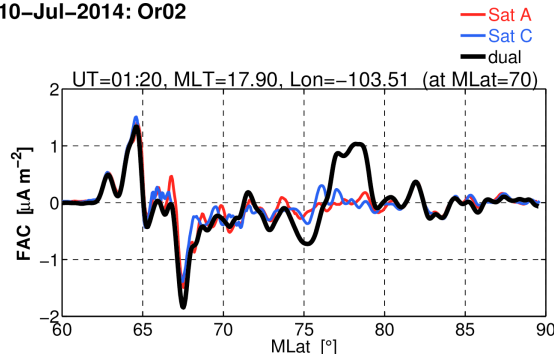
Forsyth et al., JGR, 2017



Swarm
31-May-2014: Or11



Swarm
10-Jul-2014: Or02



- Dayside FACs poleward of auroral oval
- Preference for northward IMF
- IMF By dependency

Lühr et al., *AnGeo*, 2016

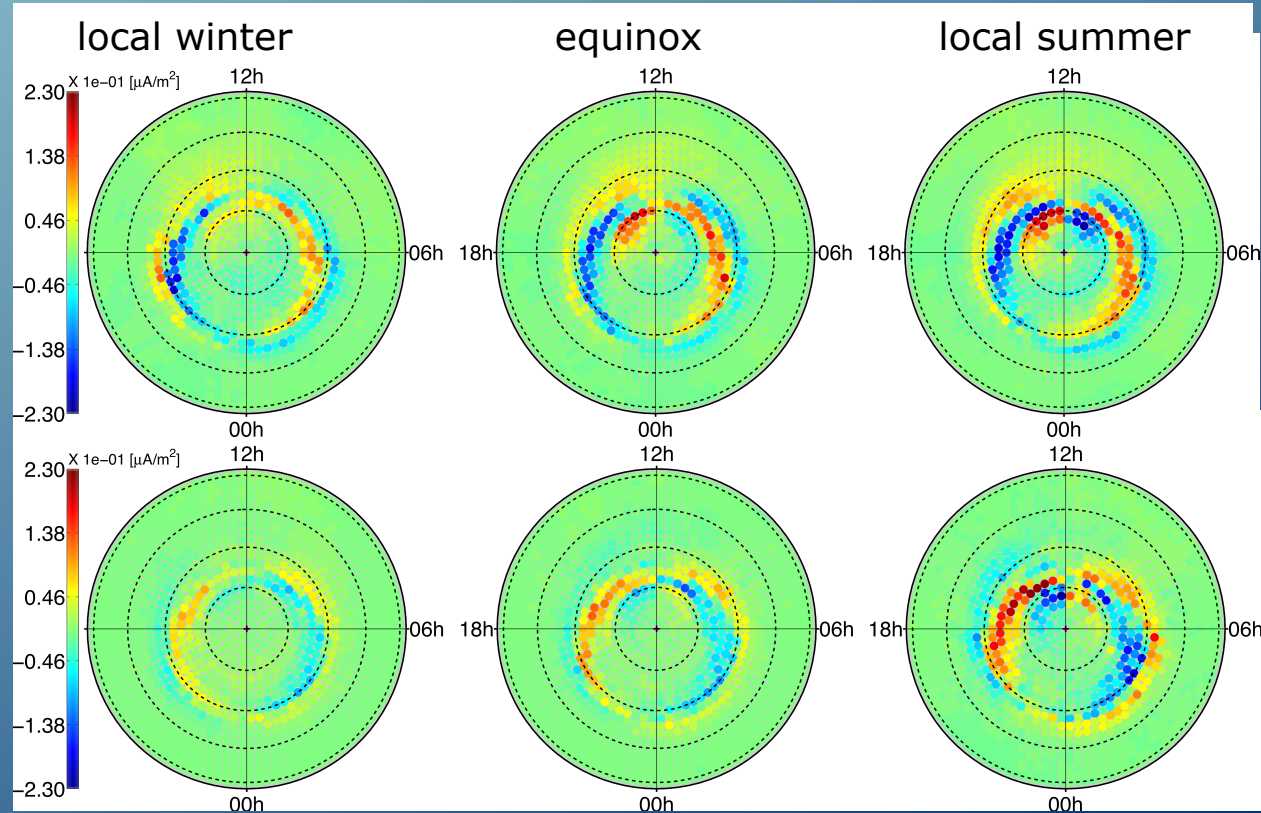
Swarm field-aligned currents (FAC)

Northern hemisphere
 $A_p < 8nT$

Southern hemisphere
 $A_p < 8nT$

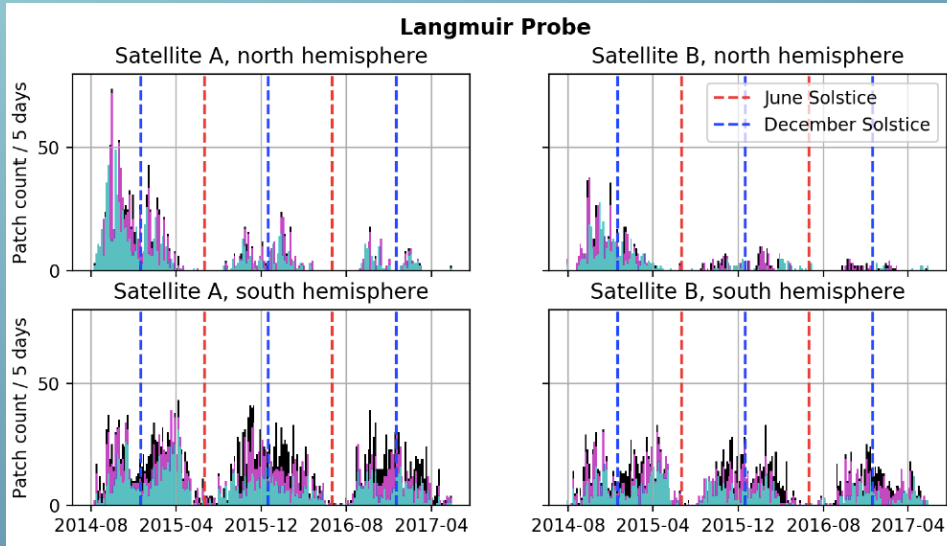
FAC and horizontal current model:
Laundal et al., *JGR*, 2018
<https://klaundal.w.uib.no/>

FAC scale analyses:
McGranaghan et al., *JGR*, 2018



Polar patch climatology

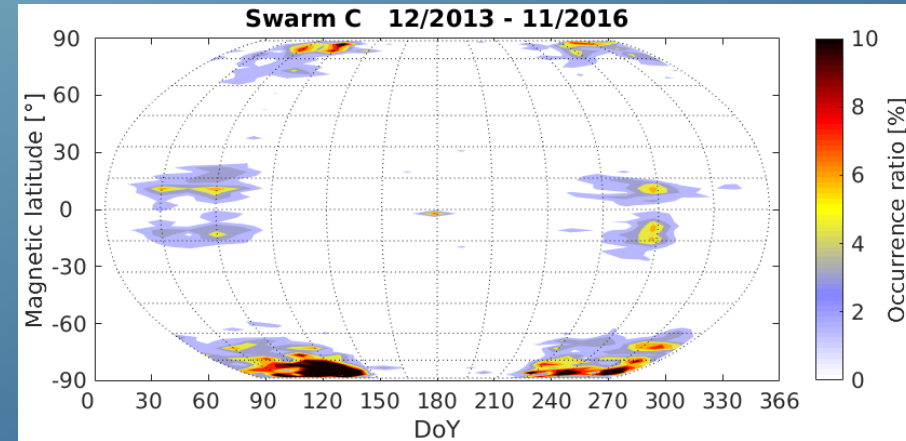
Number of identified patches in Ne



Chartier et al., *JGR*, 2018

- *Swarm* Ne + TEC polar patches (2014-2017)
- Absolute threshold + solar cycle adaptations
- Maxima at Dec. solstice/Equinox

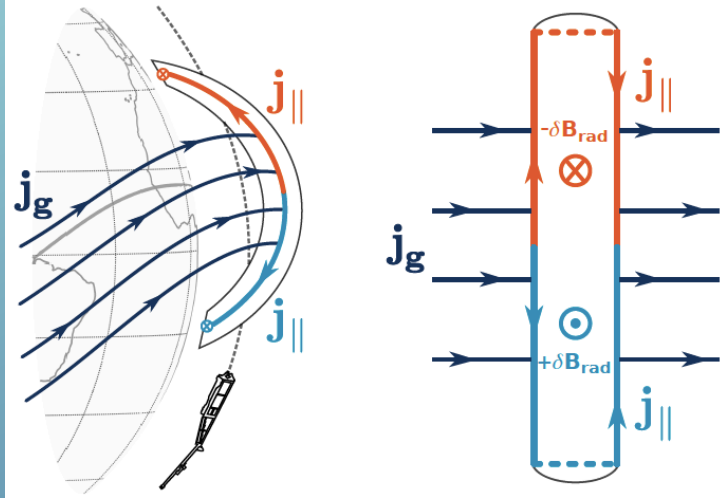
Occurrence of GPS signal losses



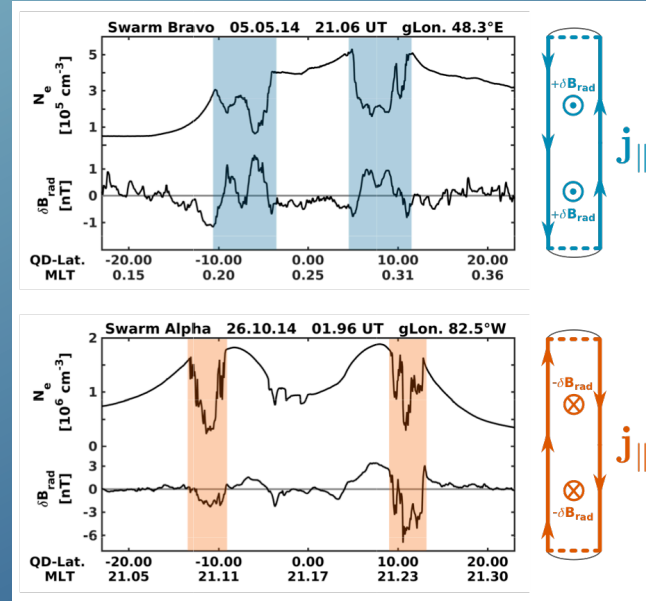
Xiong et al., *Space Weather*, 2016; *AnGeo*, 2018

- All GPS signal losses coincide with strong Δ Ne
- lat/lon/DoY distribution as ionospheric events
- **Low lats: postsunset depletions**

Postsunset equatorial F-region depletions



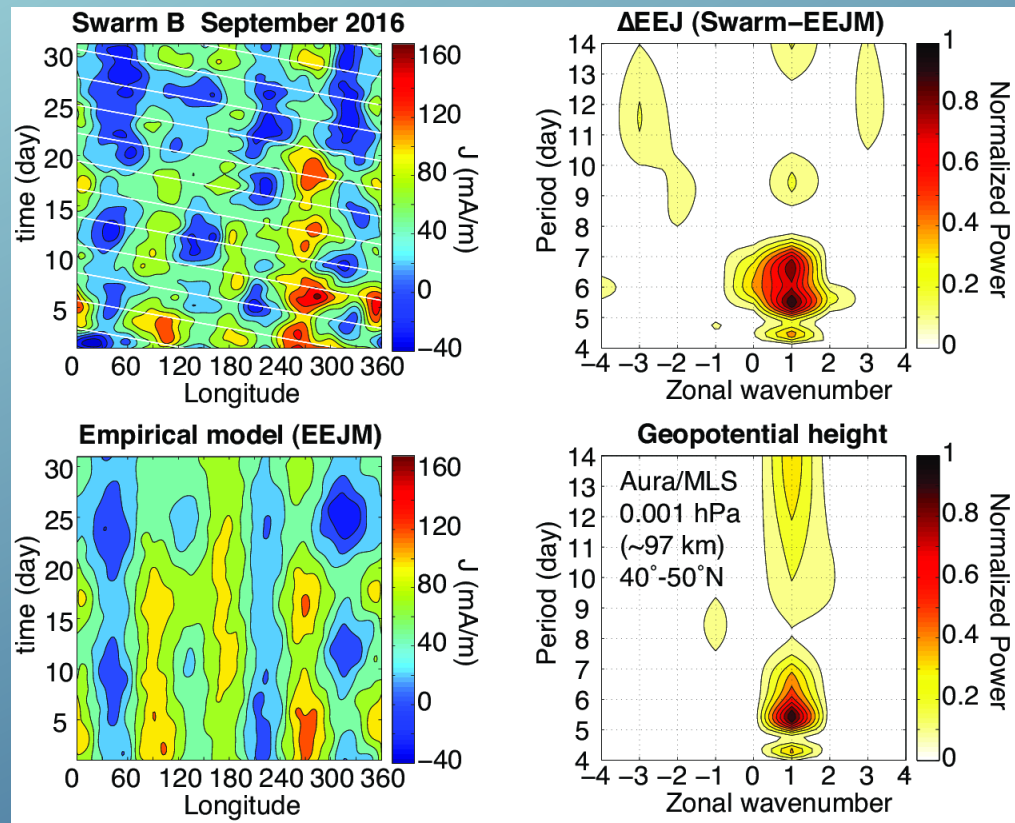
Gravity driven currents diverge poleward,
e.g.,
Aveiro et al., *GRL*, 2011
Yokoyama and Stolle, *Space Sci. Rev.*, 2017



- FACs + Poynting flux are mainly interhemispheric
- Distinct Ion/seasonal distribution
- Suggestion for hemispherically anti-symmetric conductivity

Rodriguez-Zuluaga et al., *Geophys. Res. Lett.*, 2017
Rodriguez-Zuluaga and Stolle, *Sci.Rep.*, under review, 2018

Quasi 6-day wave in EEJ (Swarm: 11:30LT – 09:00LT)



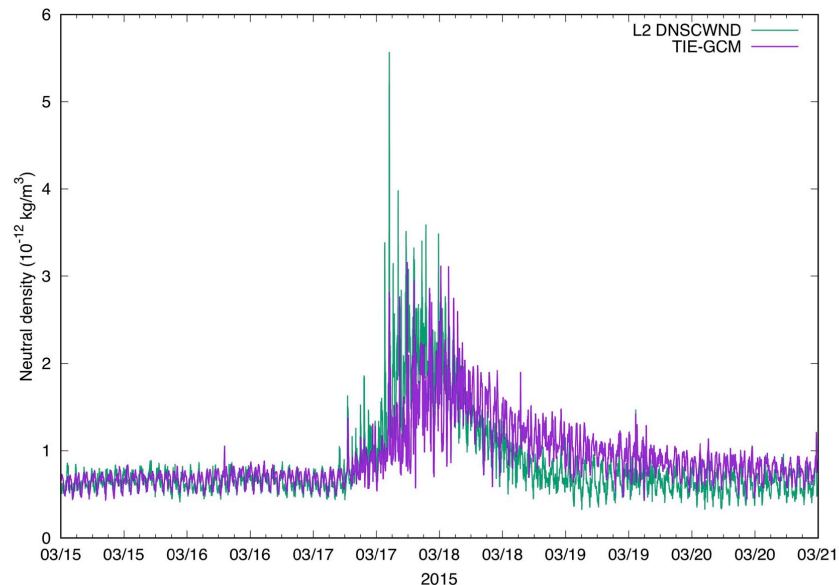
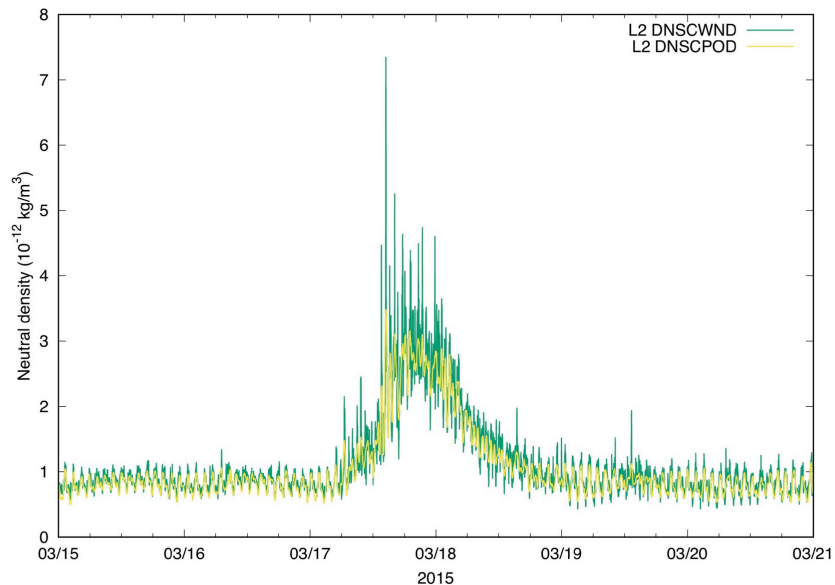
- Quasi 6-day wave is an important part of day-to-day variability of the EEJ
- 5 events detected so far in CHAMP and Swarm
- Global observation reveals longitudinal differences
- Dependence on LT, solar flux, magnitude of forcing to be investigated

Yamazaki et al., *JGR*, 2018

Swarm thermospheric density

- Derived from GPS for all three satellite (DNSxPOD)
- Combined GPS/ACC for satellite C (DNSxWND)
- Large scale variations well monitored!

Courtesy E. Doornbos and G. Lu



Conclusion: *Swarm* is a successful **multi-parameter constellation** mission to investigate Earth and its space environment also in combination with other data and models; now and in future

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Publications

Contents

Year
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2008 2014
2010 2015
2011 2016
2012 2017

earth.esa.int/swarm

swarm_feedback@esa.int

twitter.com/esa_swarm

2018

1. Akhoondzadeh M, De Santis A, Marchetti D, Piscini A, Cianchini G (2018), "Multi precursors analysis associated with the powerful Ecuador (MW=7.8) earthquake of 16 April 2016 using Swarm satellites data in conjunction with other multi-platform satellite and ground data", *Advances in Space Research*, Vol. 61, pp. 248-263
DOI: 10.1016/j.asr.2017.07.014 [BibTeX](#)
2. Archer WE and Knudsen DJ (2018), "Distinguishing Subauroral Ion Drifts From Birkeland Current Boundary Flows", *Journal of Geophysics Research: Space Physics*, Vol. 123, pp. 819–826
DOI: 10.1002/2017JA024577 [BibTeX](#)
3. Chartier AT, Mitchell CN, Miller ES (2018), "Annual Occurrence Rates of Ionospheric Polar Cap Patches Observed using Swarm", *Journal of Geophysics Research: Space Physics*, Vol. 123, pp. 2327–2335
DOI: 10.1002/2017JA024811 [BibTeX](#)

Missions

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