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A new method for deriving ionospheric currents and conductances from Swarm data

O. Amm [1], H. Vanhamäki [2,1] Liisa Juusola [1]
and K. Kauristie [1]

1) Finnish Meteorological Institute
2) University of Oulu

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- Swarm satellite mission
- SECS method for Swarm data analysis
- Results from a pilot study with synthetic data
- On Swarm **E**-field calibration and validation
- Prospects for future work

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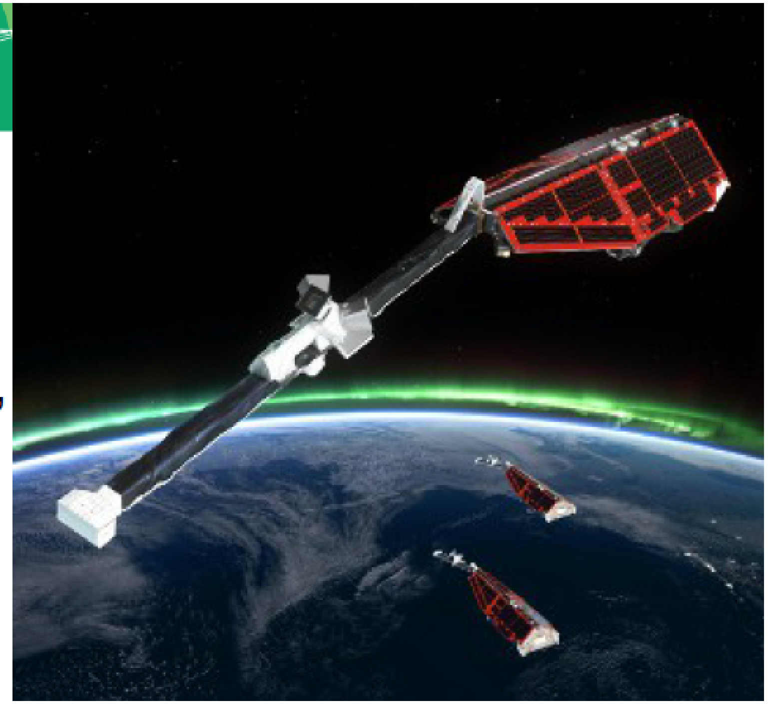
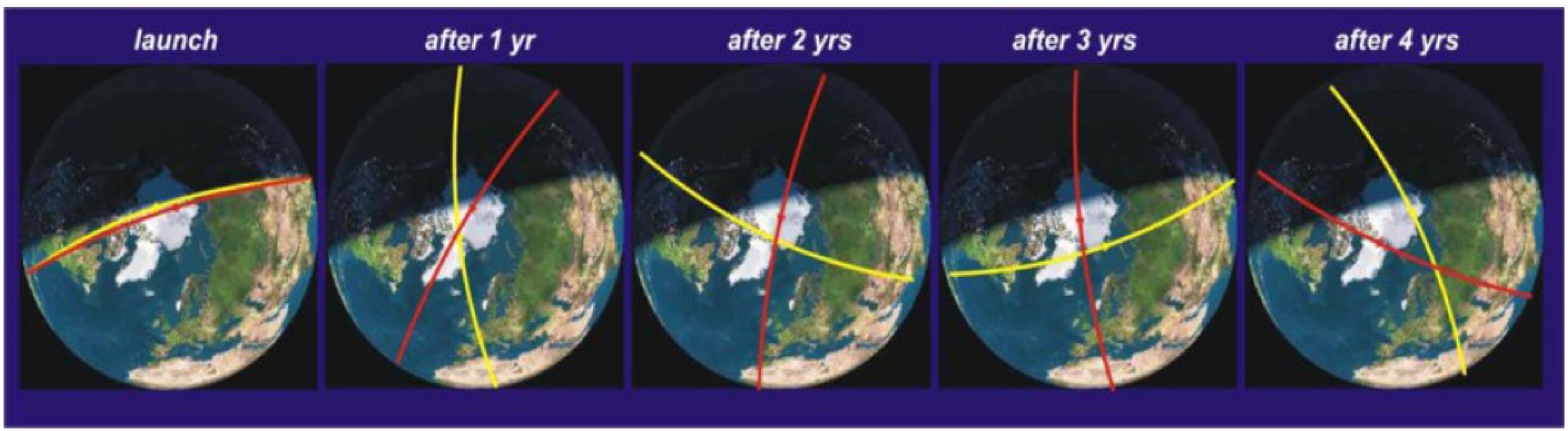
Swarm



- Launched 22.11.2013
- 3 identical satellites at low-Earth, near-polar orbits
- Planned mission time 4 years
- **Primary objectives:** 1) Geodynamo and core dynamics
  2) Lithospheric magnetisation,
  3) Electric conductivity of the mantle,
  4) Ionospheric currents
- **Secondary:** 5) Ocean circulation,
  6) Magnetic forcing of the upper atmosphere
- ***B***, ***E***, plasma density + temperature, spacecraft acceleration

Orbits

- **A+C** side-by-side at ~450 km, 87.3° inclination, ~1.4° separation in longitude, max 10 s difference in equator crossing
- **B** at ~510 km, 87.8° inclination



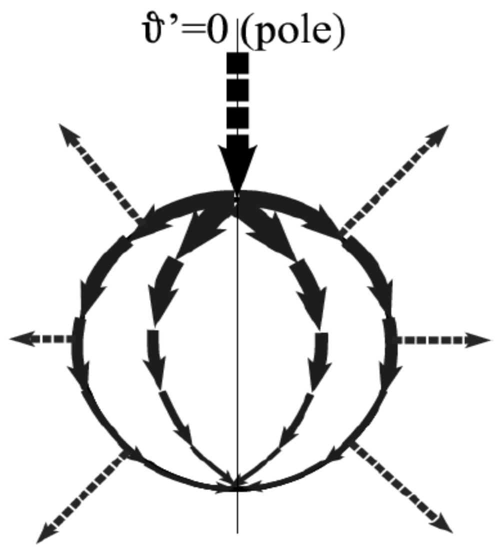
Spherical Elementary Current Systems

1) Build a grid of SECS
To the area of your
measurements

2) Adjust the intensities
Of SECS so that they fit
to the measurements

Advantage:
The resolution can be varied according to the density of observation points

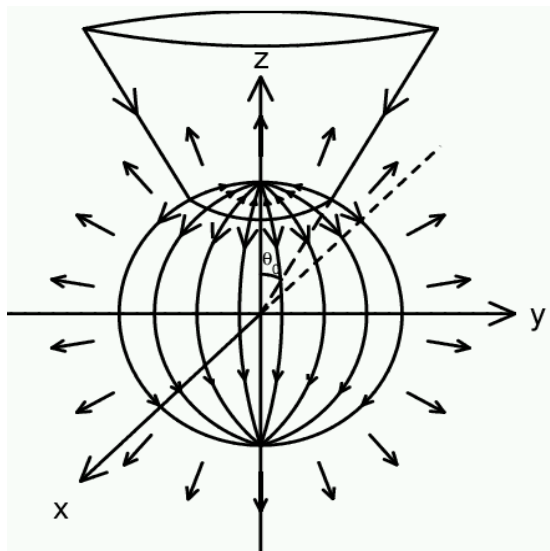
Jcf

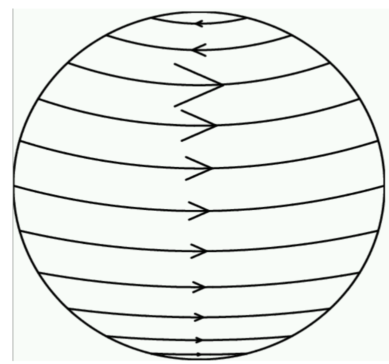


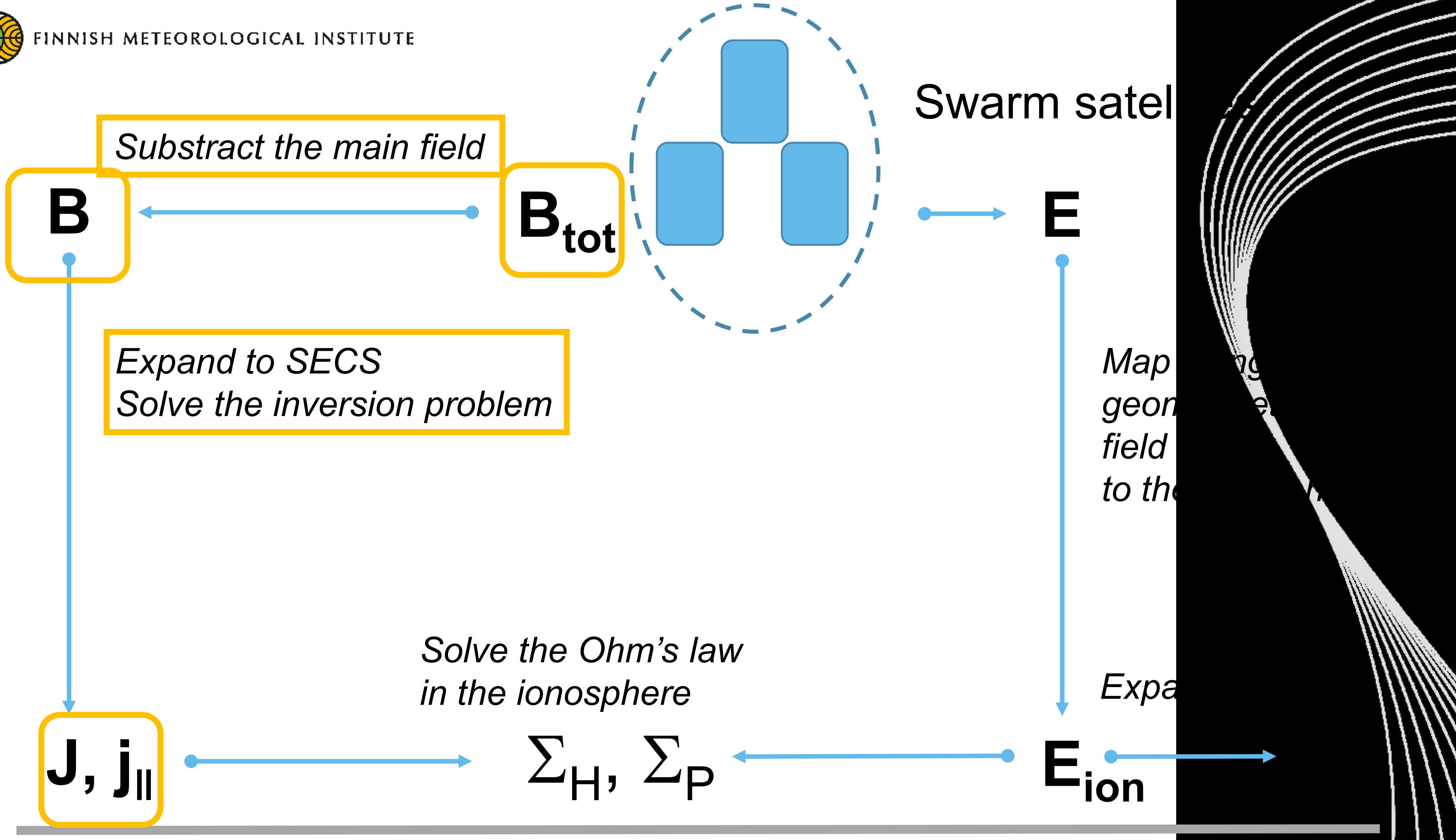
Curl-free elementary system
(with associated FACs)

Jdf

Divergence-free elementary system





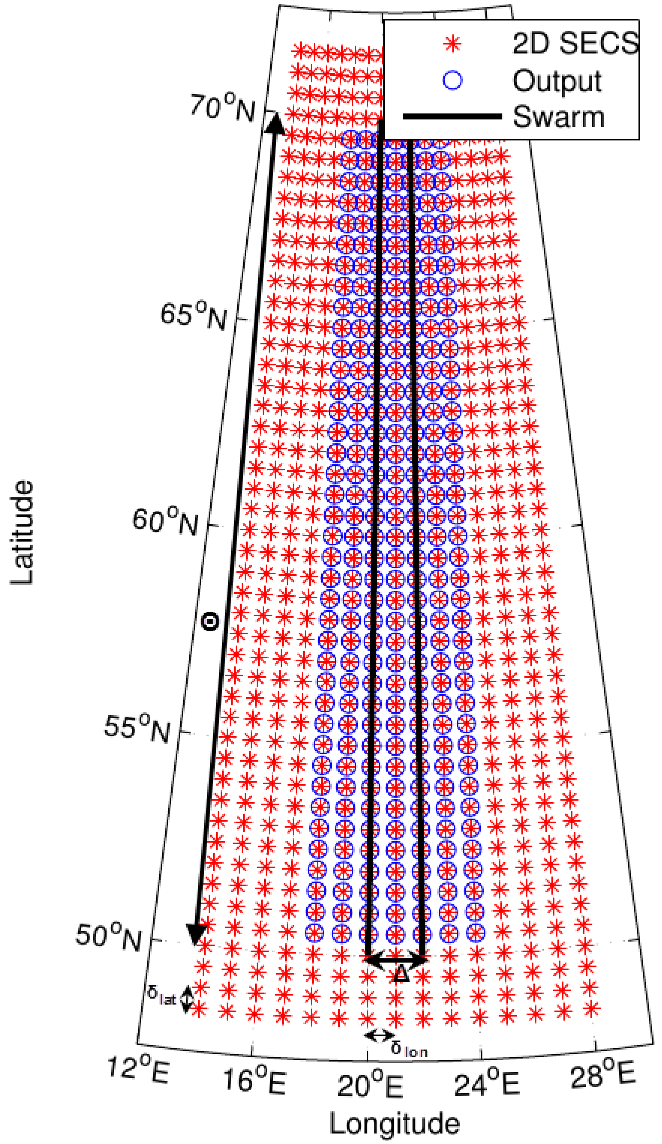


Ionospheric current layer at 110 km altitude

Steps in the analysis

1. Fit 1D div-free systems using only B_r
2. Fit 2D div-free systems using the residual B_r
3. Fit 1D curl-free systems using B_ϕ
4. Fit 2D curl-free systems using the residual B_ϕ and B_θ

1. Fit 1D curl-free systems using only E_θ
2. Fit 2D curl-free systems using the residual E_θ and E_ϕ and



stse support to science element

Exploiting synergies between Swarm and Cluster

Three simple test cases:

1. 1D electrojet, no longitudinal variations in E or Σ
2. 2D electrojet, longitudinal variations in E and Σ exists
3. A 2D current vortex

+ Virtual data from MHD simulations

Parameter	Product	Tool
Hall conductance (2D)	▲ (green)	▲ (green)
Pedersen conductance (2D)	▲ (green)	▲ (green)
Ionospheric electric field / convection (2D)	▲ (green)	▲ (green)
Ionospheric horizontal currents (2D)	▲ (green)	▲ (green)
Field-aligned currents (2D)	▲ (orange)	▲ (green)
Joule heating (2D)	▲ (green)	▲ (green)
Poynting flux (2D / 3D)	▲ (green)	▲ (green)

$$RMSerror = 100 * \frac{\sqrt{<|E_{model} - E_{result}|^2>}}{\sqrt{<|E_{model}|^2>}}.$$

	$J_\perp$	FAC	E	Σ_P	Σ_H
1D Ejet	14.8%	36.0%	4.9%	26.6%	11.6%
2D Ejet	7.9%	42.1%	2.7%	16.1%	12.0%
Vortex	18.7%	155.9%	15.1%	23.0%	22.8%

E-field calibration and validation

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The challenge

- Swarm **E**-field measured with a new method (High risk – High Gain mission)

- Original plan: Calibration with ground-based radar measurem s

- Calibration has appeared to be challenging as error in the sig depends more on the surrounding conditions than anticipated varies along the orbit)

- Ground-based radar data available only sporadically and typi only one component of **E**

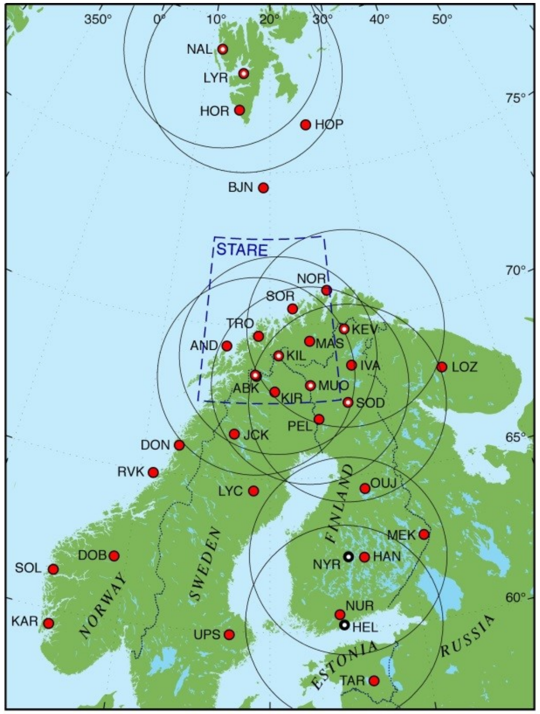
- Can also other ground-based data help in validation? **E, B,** a are anyway linked with each other.

Assumption: Swarm-SECS works OK with B

Swarm-SECS J_{df} can be validated with GB magnetometer data

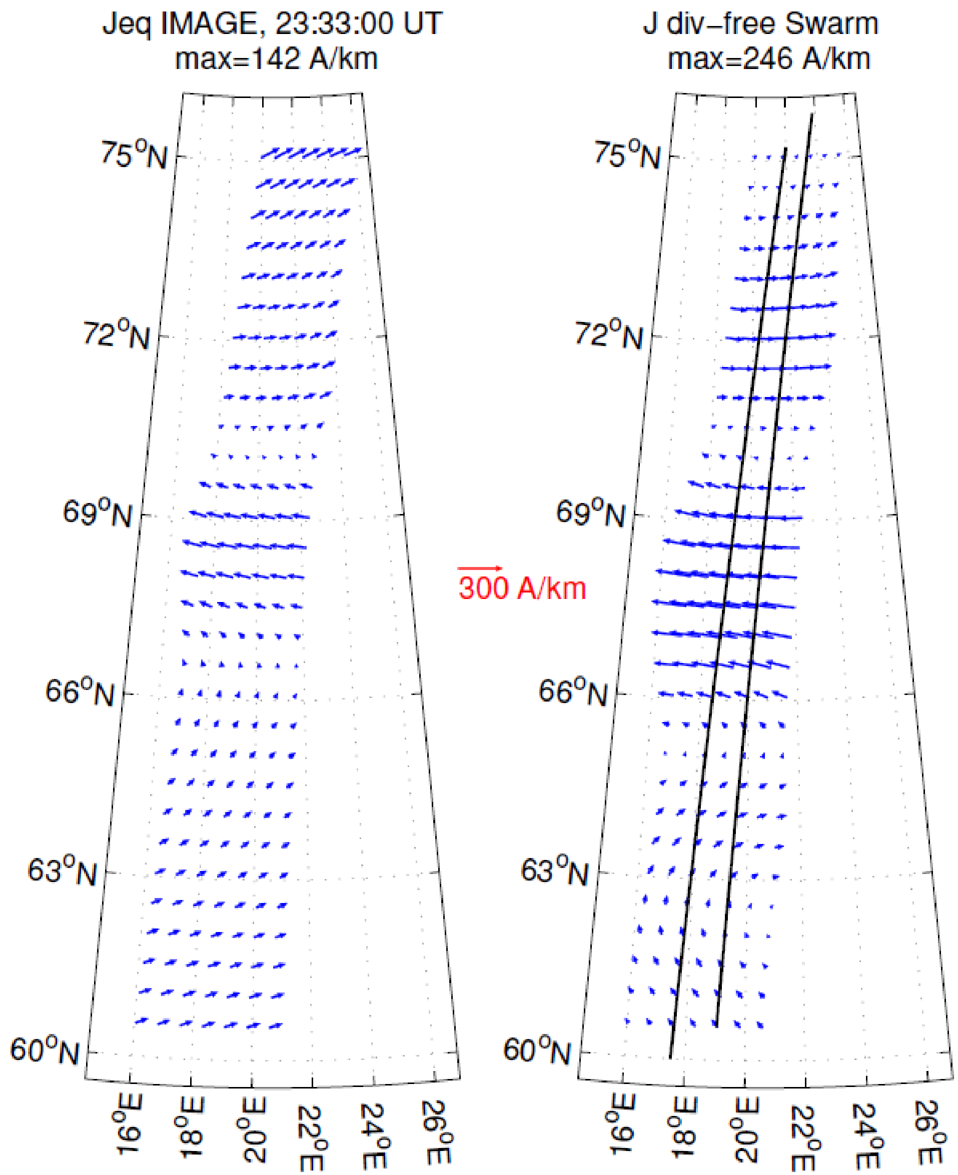
Potential causes for the differences:

- Baseline selection in IMAGE data
- Gap in the network at ~72°



Magnetometer
All-sky camera
Magnetometer and all-sky camera

February 2013



Assumption: α is typically <2

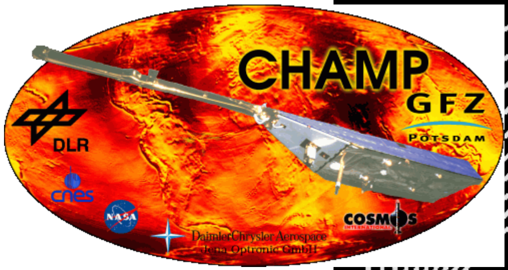
- Magnetospheric energy dissipation in the ionosphere
    - Σ_H (Hall conductance) ↔ auroral precipitation
    - Σ_P (Pedersen conductance) ↔ Joule heating

- Although Σ_H and Σ_P can themselves vary much, their ratio $\alpha = \Sigma_H / \Sigma$ varies typically in the range 0-2.

- Robinson formulas (1987) relate α and Σ_P with electron precipitatio energy flux and average energy:

- $\alpha = 0.45(\langle E \rangle)^{0.85}$
- $\Sigma_P = (40 \langle E \rangle \Psi_E^{\ 0.5}) / (16 + (\langle E \rangle)^2)$

- For example, α=4 corresponds to <E> > 10 keV, which is very ener precipitation (visible in riometer observations, but not necessary as v auroras)



The alpha parameter model

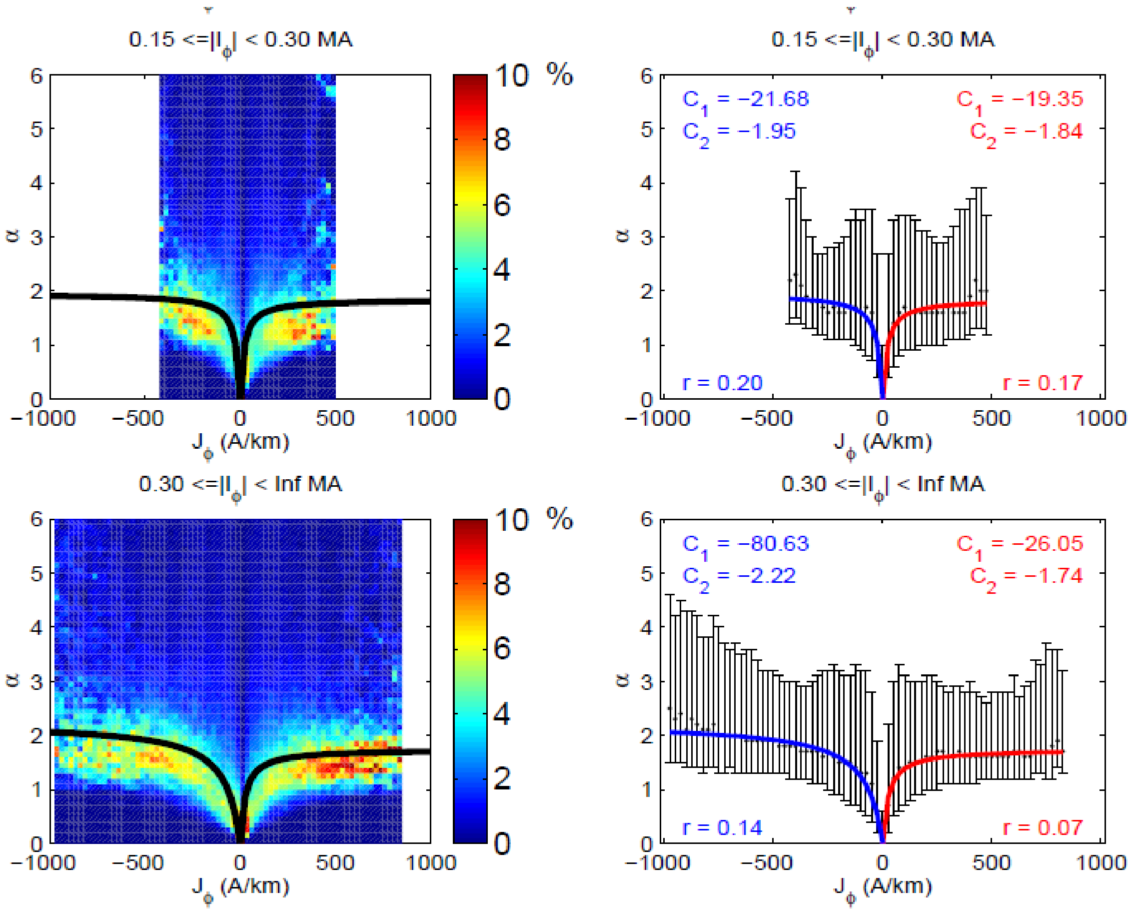
- $\alpha=\Sigma_H/\Sigma_P$, high in the regions where energetic precipitation and thus strong currents in the altitudes around 100 km
- J_ϕ and J_θ derived from CHAMP data (2001-2002, 6112 overflights)
- Use the following formulas:

$$\boldsymbol{J} = \Sigma_P \boldsymbol{E} - \Sigma_H \frac{\boldsymbol{E}\times\boldsymbol{B}}{B}$$

$$\boldsymbol{J} = \underbrace{(\Sigma_P E_\theta + \Sigma_H E_\phi)}_{=J_\theta}\hat{\boldsymbol{e}}_\theta + \underbrace{(\Sigma_P E_\phi - \Sigma_H E_\theta)}_{=J_\phi}\hat{\boldsymbol{e}}_\phi .$$

$$\alpha = \frac{\Sigma_H}{\Sigma_P} = \frac{\frac{E_\phi}{E_\theta} + \left(-\frac{J_\phi}{J_\theta}\right)}{1 - \left(-\frac{J_\phi}{J_\theta}\right)\cdot\frac{E_\phi}{E_\theta}}, \qquad \alpha = -\frac{J_\phi}{J_\theta}$$

- Assumptions:
  - **B** radial, convection **E** hor ont
  - E_ϕ <<E_θ (not applicable i ar discontinuity region)



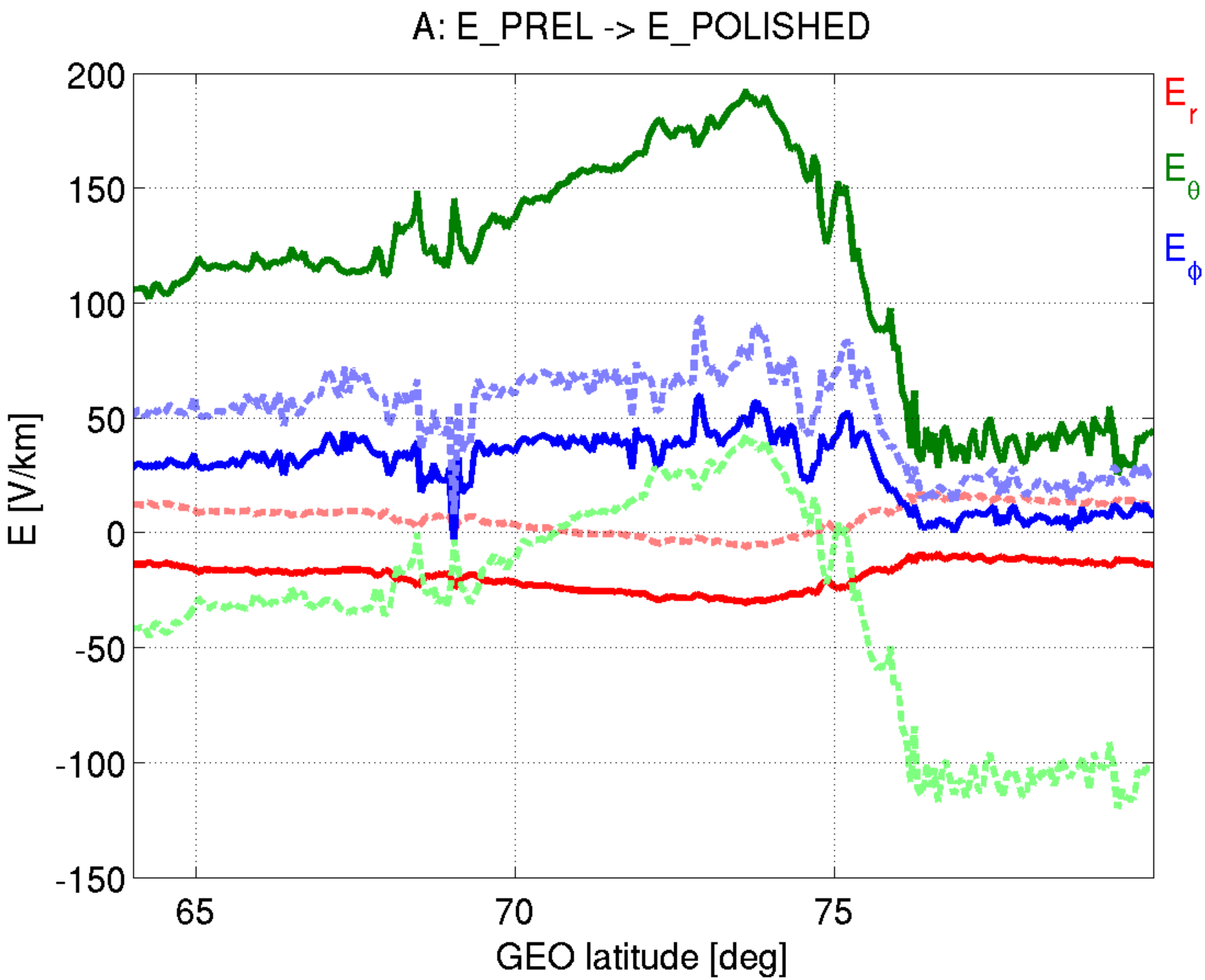
A statistical fit to Ch
which can be used a
with GB magnetome ers
measuring Jφ

$$\alpha = -\frac{J_\phi}{J_\theta} = \frac{C_2}{\frac{C_1}{|J_\phi|} - 1}$$

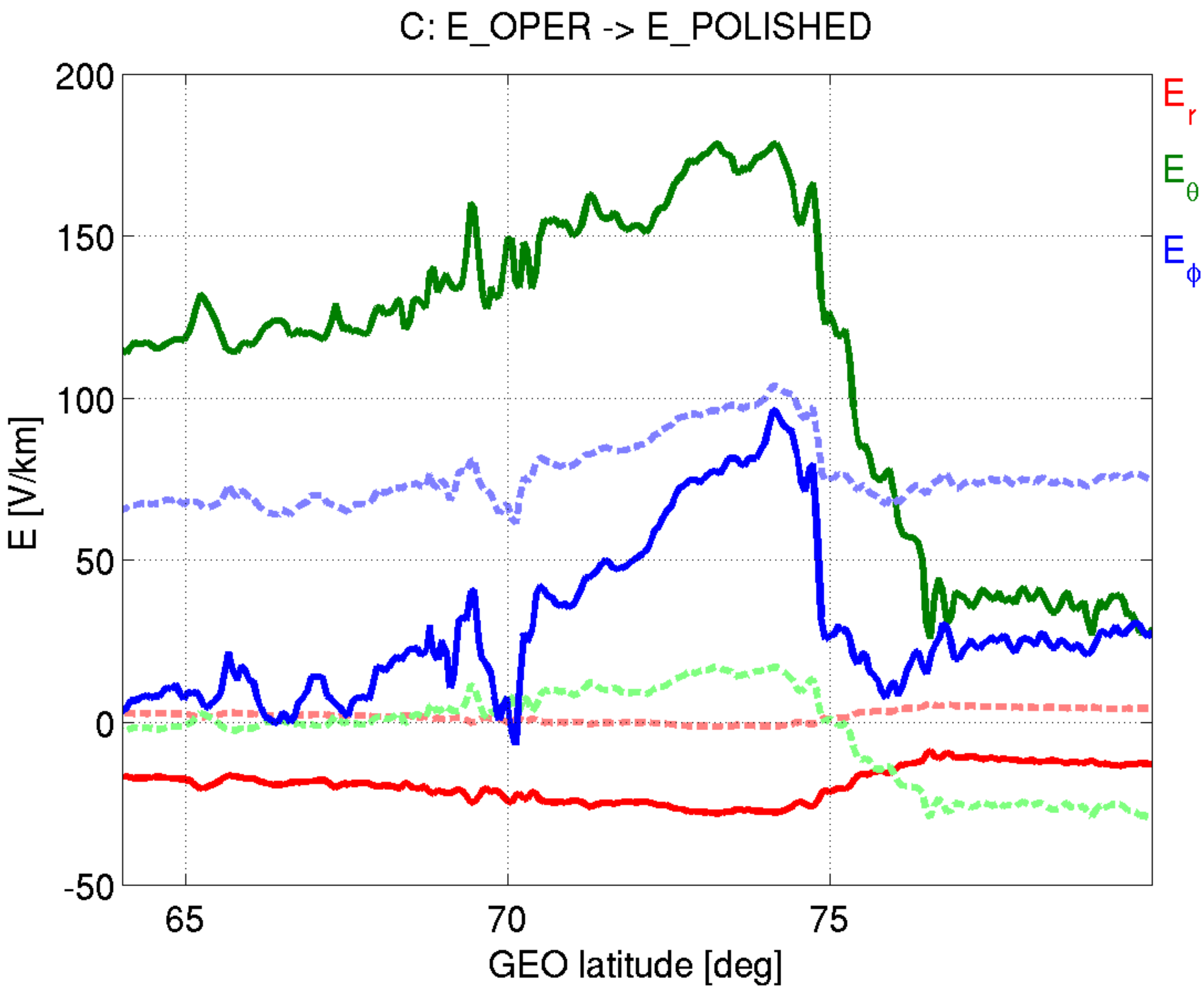
Probability of different
α=Jφ/Jθ
as function of Jφ

Bin	C_1 ($J_\phi<0$)	C_2 ($J_\phi<0$)	C_1 ($J_\phi>0$)	C_2 ($J_\phi>0$)
All	−36.54	−2.07	−14.79	−1.73
Quiet	−20.35	−2.19	−46.16	−2.53
Moderate	−21.68	−1.95	−19.35	−1.84
Active	−80.63	−2.22	−26.05	−1.74
Winter	−21.87	−1.99	−13.79	−1.42
Equinox	−49.36	−2.10	−16.55	−1.63
Summer	−18.64	−1.86	−5.88	−1.76

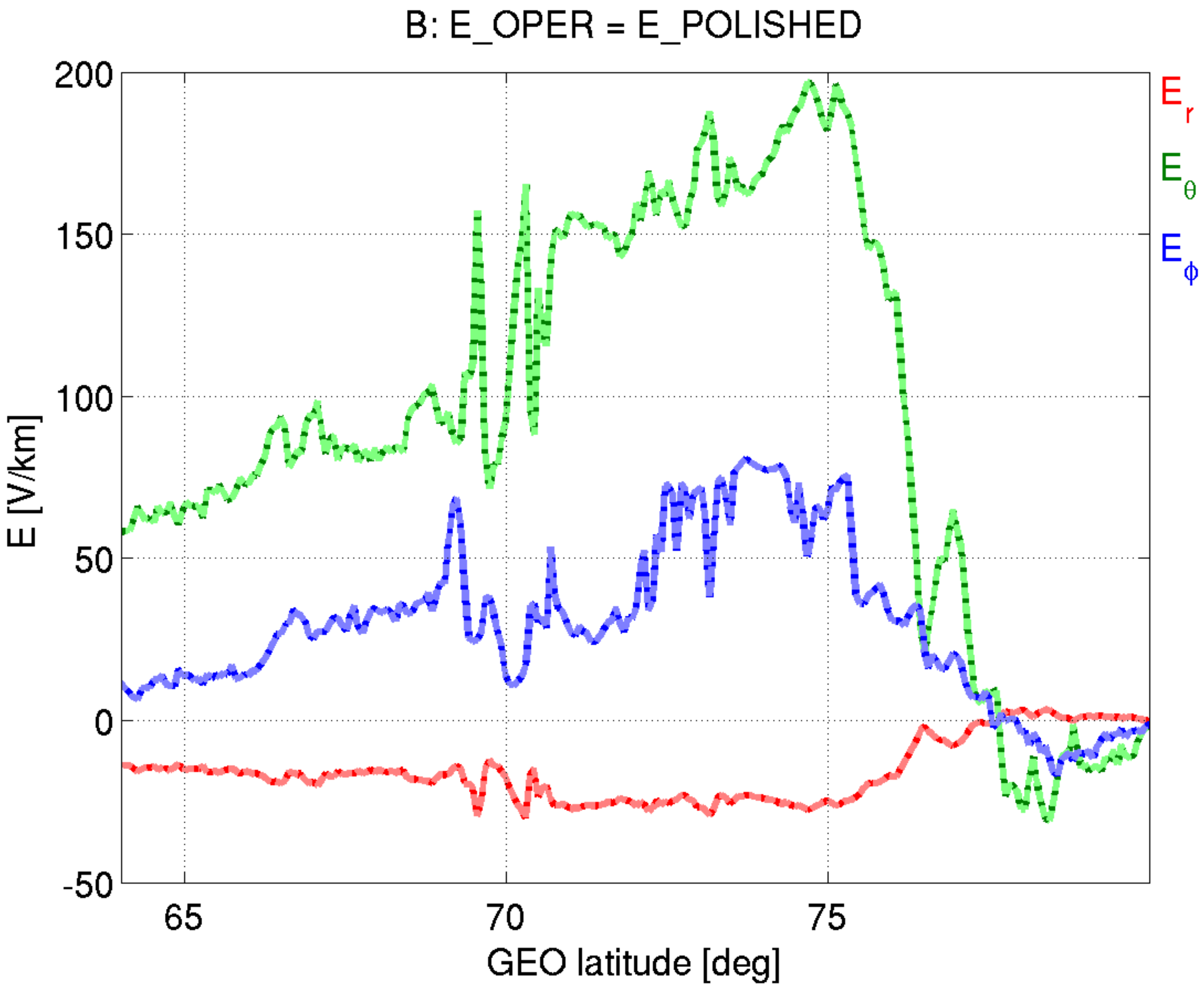
E-field ”polishing” Swarm A (Jul 30, 2014, UT 02:10)



E-field ”polishing” Swarm C

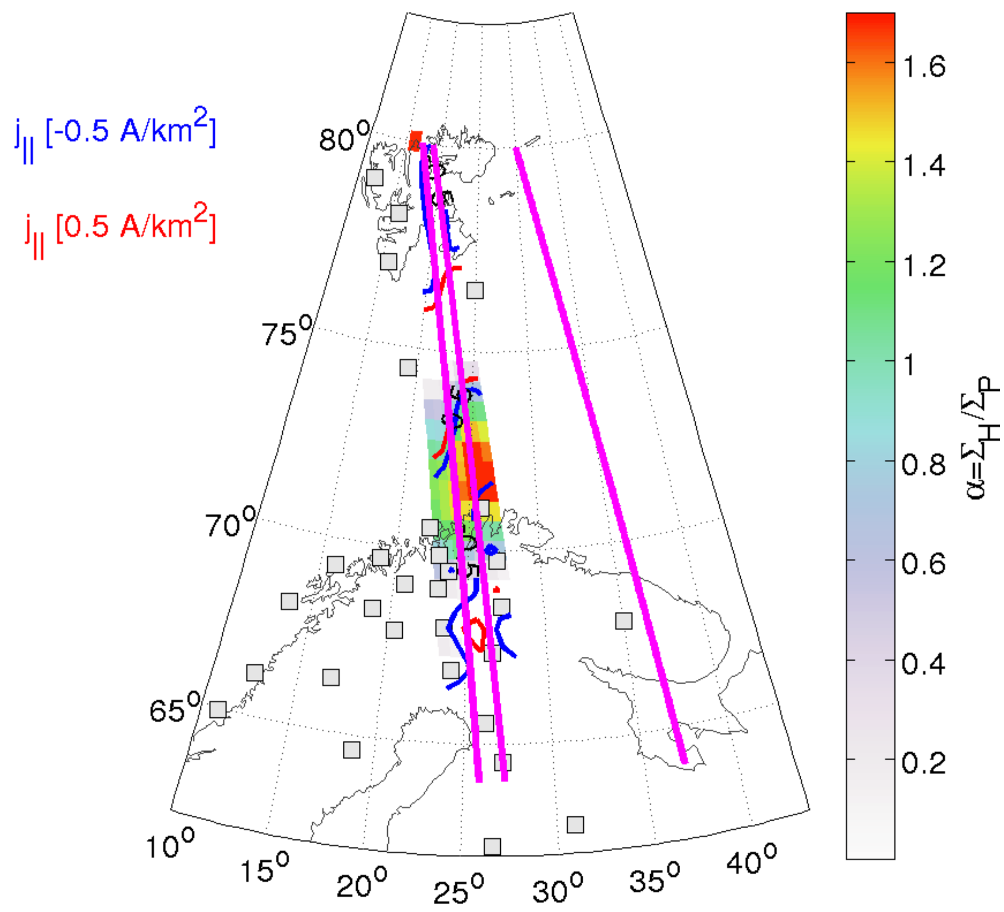


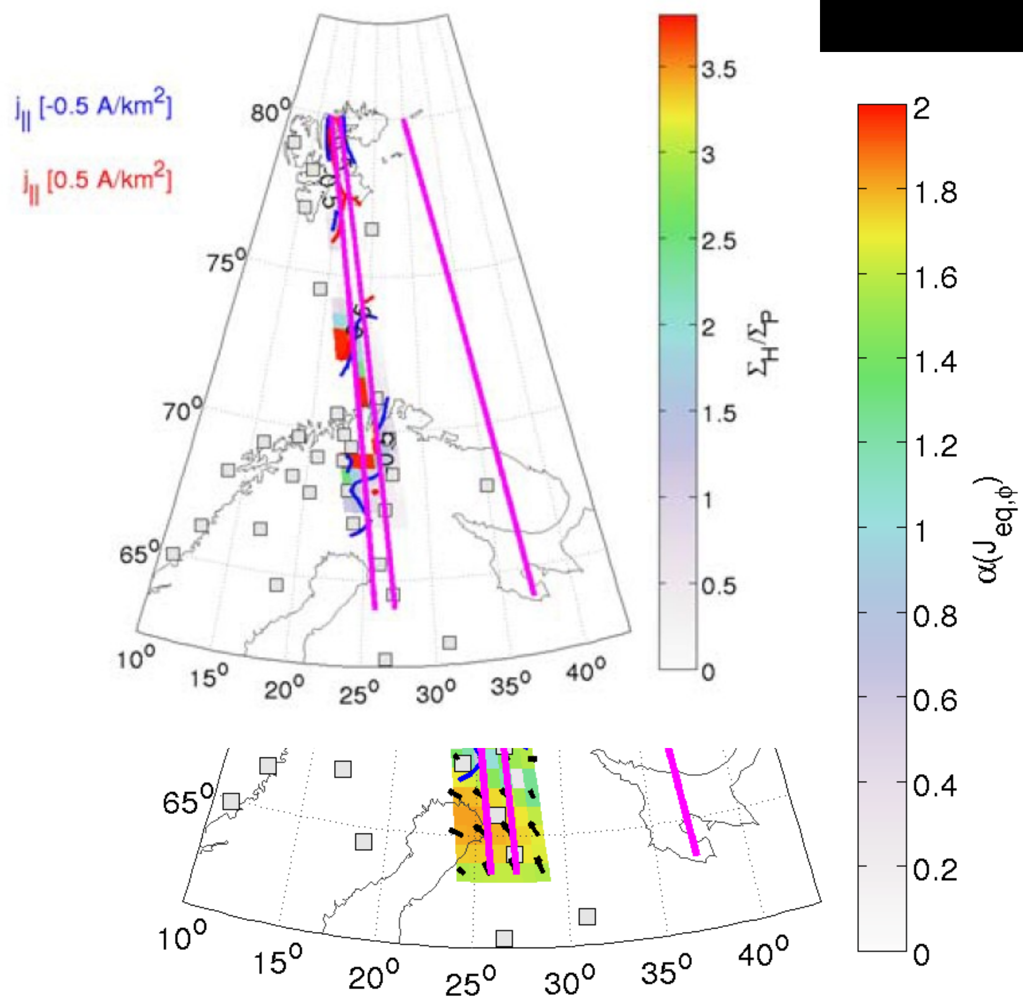
E-field "polishing" Swarm B



Checking with α-parameter

SECS, **B** and **E**-field





Conclusions and future work

SECS technique for Swarm:

- Input: **E** and **B** as input (no support from GB data needed)
- Output: 2D strips of
  - **Horizontal currents**
  - **Field aligned currents**
  - **Conductances,**
  - **Electric field,**
  - **Poynting flux**
  - **Joule heating**

Tests with Swarm B & E-

- Swarm-SECS with **B** w
- In 1D-cases α can be es with **B**-data alone
- α can help in **E** quality
- Issues:
  - In our example polishe too large
  - The grid used in Swar seems to have impact results

Next steps:

- Case studies with GB data (ISR, Themis and MIRACLE), α and **E** observations would help.
- Statistical studies ($J_{df} \leftrightarrow J_{eq}$) to find optimal SECS parameters for massive processing