FIELD-ALIGNED AND IONOSPHERIC CURRENTS INFERRED FROM TEMPORALLY AND SPATIALLY COINCIDENT ØRSTED SATELLITE, GROUND-BASED MAGNETOMETER AND SONDRESTROM ISR MEASUREMENTS

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ABSTRACT/RESUME

We have computed field-aligned and horizontal ionospheric electric currents at high northern latitudes from spatially and temporally coincident vector magnetometer measurements made onboard the low-altitude Earth-orbiting Ørsted satellite and on ground along the Greenland west coast, complemented by radar measurements made with the Sondrestrom Incoherent Scatter Radar (ISR). Fortunately, the Ørsted polebound trajectory is at times almost perfectly aligned with the best-fit great circle through the western Greenland chain of ground-based magnetometers and comes close to the magnetic field line trough the Sondrestrom radar.

We examine three cases of such coincident observations and investigate whether the trajectory-integrated field-aligned current (TIFAC), the ionospheric equivalent current and the total horizontal ionospheric current inferred from ISR measurements are consistent in direction and intensity if an appropriate Hall-to-Pedersen conductance ratio is assumed.

Sondrestrom ISR confirm that the ionospheric current was indeed in several cases predominantly east–west oriented, at least at the time of the Ørsted overflight. The equivalent and the true ionospheric Hall currents match well for the noon and midnight events but less so for the evening event. The TIFAC (closed through a Pedersen current) assumes values between 60% (daytime) and 100% (nighttime) of the equivalent ionospheric current (aasumed to be a Hall current). This is in agreement with typical daytime and frequently observed nighttime Pedersen/Hall conductance ratios.

1. DATA SELECTION

The events must fulfill the following criteria in order to qualify for inclusion in our study:

- The Ørsted trajectory, mapped along the field lines down to 110 km altitude, falls within a narrow strip centered on the Greenland west coast magnetometer chain (Fig. 1, full blue circles). The strip is approximately 700 km wide at the southern tip of Greenland and becomes narrower towards the pole. This allows only data from ascending passes to be considered.
- Ørsted attitude and vector magnetometer data are sufficiently continuous (gaps must not exceed 5 data points, equivalent to 42 km along the trajectory).
- The Sondrestrom ISR (Fig. 1, blue diamond) was operated in a mode which provides good height resolution of the E region (90–140 km) and allows determination of a fully resolved horizontal electric current vector.

Seven events fulfilled the criteria. Four of them were discarded because of poor radar return signals which were not suitable for quantitative analysis. The remaing three cases are discussed here in more detail. One of them falls into the noon sector (11 MLT), one into the evening sector (19 MLT) and one into the midnight sector (23 MLT).

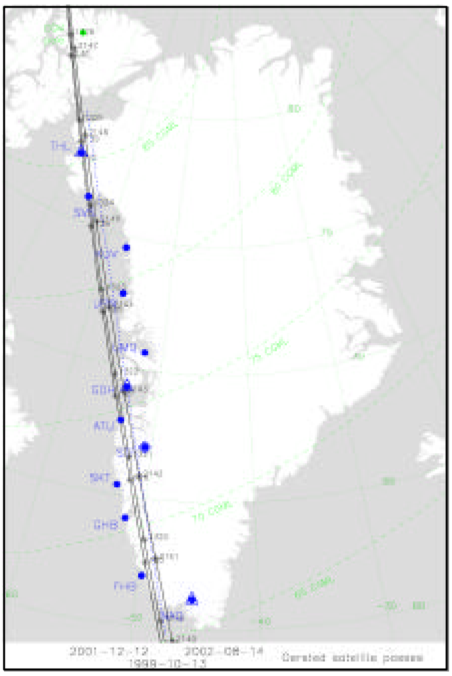

Figure 1. *The three ascending Ørsted passes over western Greenland considered here, mapped down to 110 km altitude (solid black lines, UT markers along the traces). Center: Oct 13, 1999, pass; left: Dec 12, 2001, pass; right: Aug 14, 2002, pass. Dotted straight line: best-fit great circle through magnetometer sites.*

2. CURRENT COMPUTATION METHOD

2.1. FAC density along a single satellite trajectory

We assume the FACs to form a sequence of parallel current sheets. Of its two vector components – one oriented parallel and the other perpendicular to the satellite trajectory – we consider only the latter. The magnetic field gradient along the projection of the satellite trajectory on a plane perpendicular to the geomagnetic field provides one of the components of $\nabla\times\mathbf{B}$. The second field-perpendicular component vanishes because it is aligned with the current sheets assumed to prevail. Finally, the field-parallel component vanishes because we consider only FACs. The FAC density (of the sheets perpendicular to the trajectory) is then derived from $\nabla\times\mathbf{B}$ *via*

$$m_0 \, j_{\|} = \frac{\partial B_{cross}}{\partial s} \tag{1}$$

and mapped down to 110 km reference altitude. Inspection of Ørsted magnetic field data revealed that we practically never observe significant magnetic perturbations equatorward of 55º corrected geomagnetic latitude (CGML) during the Ørsted passes selected. For each satellite pass we integrated the FAC density along the trajectory, starting at 55º, in order to obtain a trajectory-integrated FAC (termed TIFAC) at every point along the trajectory as outlined in [2].

2.2. Ionospheric Hall current density inferred from ground-based magnetometer data

The equivalent ionospheric current, assumed to form a thin horizontal sheet at 110 km above the ground, was determined by applying a method proposed in [1] but slightly modified for this study. The method uses the ground magnetic field observations taken at the Greenland west coast stations in a coordinate system in which the H-component is aligned with the best-fit great circle through the west coast chain and the Z-component points vertically down. A suitable combination of the H- and Z-components renders, under certain conditions, a magnetic field variation from which the internal (induced) contribution has been removed. The magnetic field corrected in this way (only H_{ext} and Z_{ext} remain) is then used to determine that part of the equivalent ionospheric current which flows perpendicular to the magnetometer chain. We assume this current to be a Hall current driven by an electric field oriented parallel to the magnetometer chain.

2.3. Trajectory-integrated FAC (TIFAC) and ionospheric currents

If the FAC system consists of sheets uniformly extended across the magnetometer chain then the FAC sheets must be closed in the ionosphere *via* Pedersen currents flowing parallel to the chain. Under the assumption that FACs are negligible equatorward of 55º CGML the local Pedersen current must match the local TIFAC. The same electric field that drives the Pedersen current along the chain also drives the ionospheric Hall current across the chain.

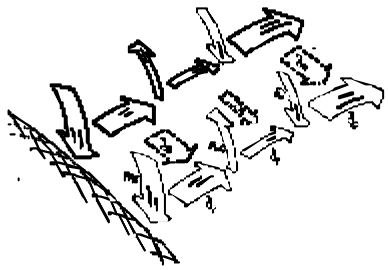

Figure 2: *Closure of TIFAC sheets through ionospheric Pedersen currents under the assumption that no currents flow equatorward of a certain latitude (55º corrected geomagnetic latitude assumed).*

The Hall-to-Pedersen current ratio, and consequently the Hall-to-TIFAC ratio, have to be identical to the Hall-to-Pedersen conductance ratio (SH/SP) if our sheet current assumption holds since they are driven by the same electric field:

$$\begin{aligned} J_P &= \Sigma_P \, E \\ J_H &= \Sigma_H \, E \\ J_P &= TIFAC \\ \Rightarrow \quad \frac{TIFAC}{J_H} &= \frac{\Sigma_P}{\Sigma_H} \end{aligned} \tag{2}$$

3. DATA FROM TWO SAMPLE EVENTS

In the two samples shown in Fig. 3 and Fig. 4 the FAC density varies significantly along the satellite trajectory and alternates on short scale between upward (white) and downward (black) orientation. From this up-and-down sequence it is not immediately obvious how the density of the current closure in the ionosphere (Pedersen current) should vary. The TIFAC distribution gives a clearer picture. An upward TIFAC must feed into an ionospheric Pedersen current which, according to our assumption, must be equatorward oriented and the associated Hall current westward oriented. Similarly, a downward TIFAC must be associated with a poleward directed Pedersen current and an eastward directed Hall current.

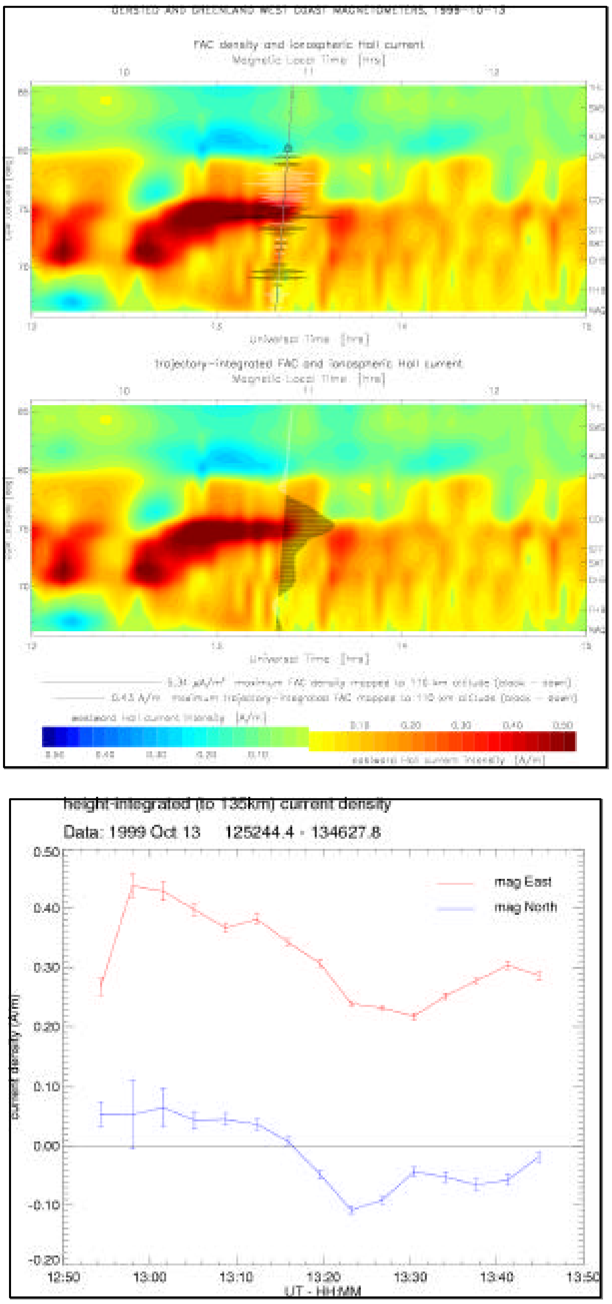

Figure 3: *Top: Ionospheric equivalent current versus time and corrected geomagnetic latitude (color-coded), Ørsted trajectory with FAC density (top) and TIFAC (bottom), mapped down to 110 km Bottom: Height-integrated eastward and northward ionospheric current inferred from ISR measurements. The heavy arrows mark the time of the Ørsted pass.*

Table 1 reveals that the height-integrated ionospheric currents were in two cases predominantly east–west oriented. The directions inferred from the various instruments (space borne and ground-based magnetometers and the radar) are consistent in all cases. A downward TIFAC corresponds to an eastward equivalent and mainly eastward total ionospheric current, and an upward TIFAC corresponds to a westward equivalent and mainly westward total ionospheric current. The current densities are large in the Oct 13 (noon) and Aug 14 (evening) events, and much smaller in the Dec 12 (midnight) event, probably because of the presence resp. absence of ionizing UV-EUV sunlight.

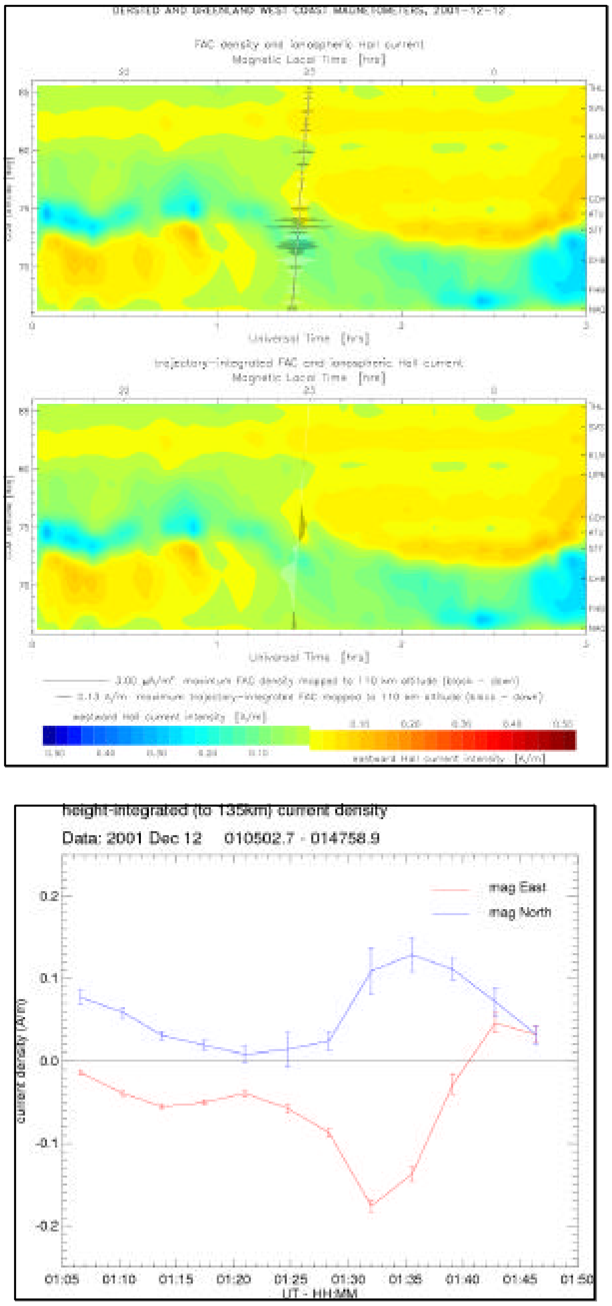

Figure 4*: As Figure 3 but for the Dec 12, 2001 case.*

Table 1: *Current densities above Sondrestrom inferred from ground-based magnetometers (equiv. ionos.), the Ørsted satellite (TIFAC) and the incoherent scatter radar (true ionos.).*

Date / time	Current type	Current density
1999-10-13	equiv. ionos.	0.26 A/m east
≈ 11 MLT	TIFAC	0.17 A/m down
	true ionos.	0.27 A/m east 0.08 A/m south
2001-12-12	equiv. ionos.	0.04 A/m west
≈ 23 MLT	TIFAC	0.04 A/m up
	true ionos.	0.07 A/m west 0.02 A/m north
2002-08-14	equiv. ionos.	0.14 A/m east
≈ 19 MLT	TIFAC	0.10 A/m down
	true ionos.	0.23 A/m east 0.20 A/m north

Table 2 lists the measured total ionospheric, equivalent ionospheric and TIFAC (the latter is considered equal to the Pedersen current). Furtheron, one of them is computed given the other two and taking into account that the complete current system must be divergence free. We also assume that the equivalent current is a Hall current perpendicular to the Pedersen current. The agreement between the results is not perfect but encouraging, given that we used the restrictive assumption of infinitely extended sheet currents.

Table 2: *Total ionospheric, Pedersen (@ TIFAC) and equivalent ionospheric (@ Hall) currents above Sondrestrom inferred directly from measurements (upper row for each event row, source in italics), and total ionospheric, Pedersen (@ TIFAC) and equivalent ionospheric (@ Hall) currents indirectly obtained from combinations of the two other data sources, taking into account the absence of current divergence (lower row in each event row, the two sources in italics).*

Date / time	total ionosph.	Pedersen @ TIFAC	equiv. ionosph.
1999-10-13	0.28 A/m *ISR*	0.17 A/m *Ørsted*	0.26 A/m *magnetom.*
≈ 11 MLT	0.31 A/m *Ørsted + mags*	<0.07 A/m *ISR – mags*	0.22 A/m *ISR – Ørsted*
2001-12-12	0.07 A/m *ISR*	0.04 A/m *Ørsted*	0.04 A/m *magnetom.*
≈ 23 MLT	0.06 A/m *Ørsted + mags*	0.06 A/m *ISR – mags*	0.06 A/m *ISR – Ørsted*
2002-08-14	0.30 A/m *ISR*	0.10 A/m *Ørsted*	0.14 A/m *magnetom.*
≈ 19 MLT	0.17 A/m *Ørsted + mags*	0.16 A/m *ISR – mags*	0.22 A/m *ISR – Ørsted*

4. SUMMARY AND CONCLUSIONS

We have examined three cases of temporally and spatially coincident observations from the Ørsted LEO satellite, the Sondrestrom Incoherent Scatter Radar and the Greenland west coast chain of ground-based magnetometers. We inferred the trajectory-integrated field-aligned current (TIFAC) from satellite magnetometer measurements, the true horizontal ionospheric current from ISR data and the ionospheric equivalent current from ground-based magnetometer recordings.

The three methods applied to derive current density and orientation are completely different and rest on different physical principles. The methods require their very specific and rather severe physical assumptions. Nevertheless, a direct comparison between the electric currents in the ionosphere above Sondrestrom exhibits encouraging agreement between results obtained using different measurement principles and inversion methods. The intensities as well as the orientations of the currents are largely in accordance with the simple model assumed here.

The remaining descrepancies are probably due to deviations of the real physical conditions from the idealized assumed conditions. The underlying assumptions may have been violated in the sense that

- Hall and/or Pedersen conductances exhibit substantial spatial gradients.
- The assumption of infinite sheet currents is invalid.
- Ionisation of the upper atmosphere is not only an effect of solar illumination but also of energetic particle precipitation the characteristics of which have substantial impact on the SH/SP ratio.

We conclude that comparison between different methods enables us to test whether the current densities inferred from different data sources are consistent with the assumption of sheet currents.

5. REFERENCES

1. Popov V.A. et al., *Earth Planets Space*, Vol. 53, 129–137, 2001.
2. Watermann J. et al., in “First CHAMP Mission Results”, C. Reigber, H. Luehr, P. Schwintzer (eds.), 361–368, 2003.