Challenging the Multiple Definitions of Auoral Electrojets

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Abstract

We present a comparison between magnetic field perturbations from Hall and divergence free currents. Historically the auroral electrojets have been studied using an array of techniques. The workhorse has been, and remains to be, the groundbased magnetometers. As a consequence several different definitions of what the electrojets are; Ground based magnetic field perturbations rotated 90 degrees. Hall currents or Hall, Pedersen and field aligned currents or divergence-free currents. It is analytically known when the equivalent current produced by magnetic field measurements on ground are identical to the Hall current i.e. Fukushima's theorem. However, the inherent assumptions do not hold in reality. The purpose of this study is to understand when, where and why these concepts agree and disagree. The comparison is done using MHD simulation (Gamera) which provides contributions to the magnetic perturbation from various decompositions of the ionospheric currents.

Historical definitions

The term auroral electrojet was first suggested by [Chapman 1951] as referring to the ionospheric current on a spherical shell necessary to produce the observed magnetic perturbation on ground. In the following decade the first maps of equivalent ionospheric currents were conducted using ground magnetometers e.g. [Akasofu et al. 1965] and references therein.

A common technique of retrieving the equivalent ionospheric electric current is to rotate the horizontal magnetic field perturbations 90 degrees clockwise [Baumjohann et al. 1977].

[Fukushima 1994] states that the equivalent current is a Hall current under the assumption of radial magnetic field lines and uniform ionospheric conductance.

[Baumjohann 1982] explain the electrojets in terms of Hall currents.

[Unitedt and Baumjohann 1993] explain the equivalent currents/electrojets as a divergence-free current containing both Hall and Pedersen contributions.

Conclusion

The auroral electrojets are historically studied using ground magnetometers which only observe magnetic perturbation from the divergence-free part of the ionospheric electric current containing contributions from both Hall and Pedersen.

We show that the divergence-free part of the Pedersen current can have a large impact on the magnetic perturbation on ground. It is therefore not safe to assume that the ionospheric equivalent currents are mainly Hall currents.

We hope to continue this study to sort out the terminology used and achieve more correct usage of magnetic field perturbation measurements when studying ionospheric electrodynamics.

Analysis

The horizontal ionospheric electric current can be expressed in terms of Hall and Pedersen currents or divergence-free (DF) and curl-free (CF) currents.

$$\boldsymbol{J}_\perp = \Sigma_P \boldsymbol{E}_\perp + \Sigma_H \left(\boldsymbol{E} \times \hat{\boldsymbol{b}}\right) = \boldsymbol{J}_{DF} + \boldsymbol{J}_{CF}$$

Using the Hall and Pedersen conductance and horizontal electric field from a MHD simulation (Gamera and OpenGGCM) as input into a model of the ionospheric electrodynamics (Lompe) we are able to determine the DF part of the Hall and Pedersen current.

Lompe uses Spherical Elementary Current Systems (SECS) to link magnetic field perturbations (ground/space), convection and conductance measurements via. Ionospheric Ohm's law. The result is a model of the ionospheric electric field given in terms of SECS.

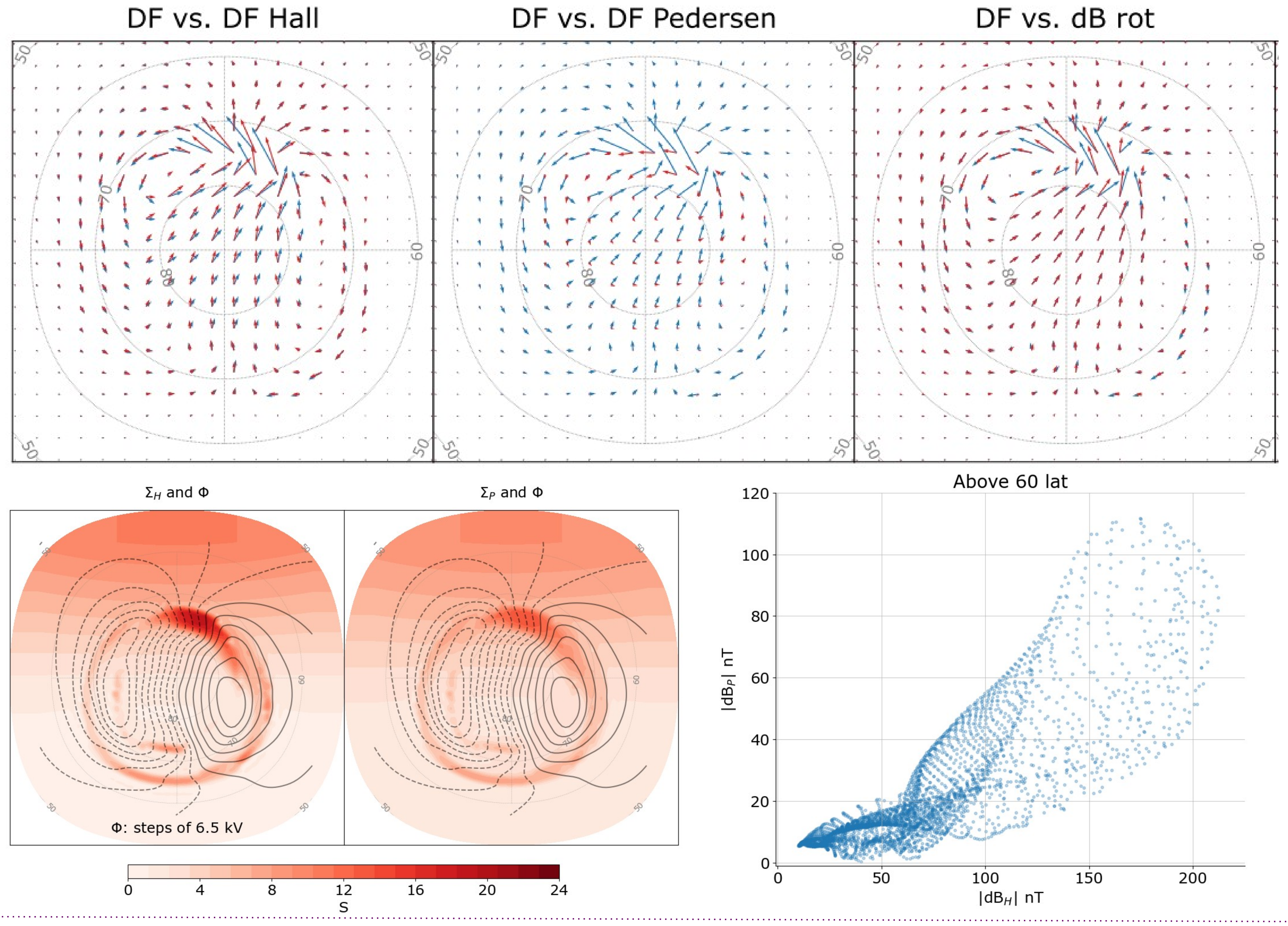
The $\boldsymbol{J}_{DF}$ can be expressed using SECS and by linking it to the electric field described by Lompe using the curl of $\boldsymbol{J}_\perp$,

$$(\nabla \times \boldsymbol{J}_\perp) = (\nabla \times \boldsymbol{J}_{DF}) = (\nabla \Sigma_P) \times \boldsymbol{E}_\perp + \Sigma_H \left[\nabla \times \left(\boldsymbol{E}_\perp \times \hat{\boldsymbol{b}}\right)\right] + (\nabla \Sigma_H) \times \left(\boldsymbol{E}_\perp \times \hat{\boldsymbol{b}}\right)$$

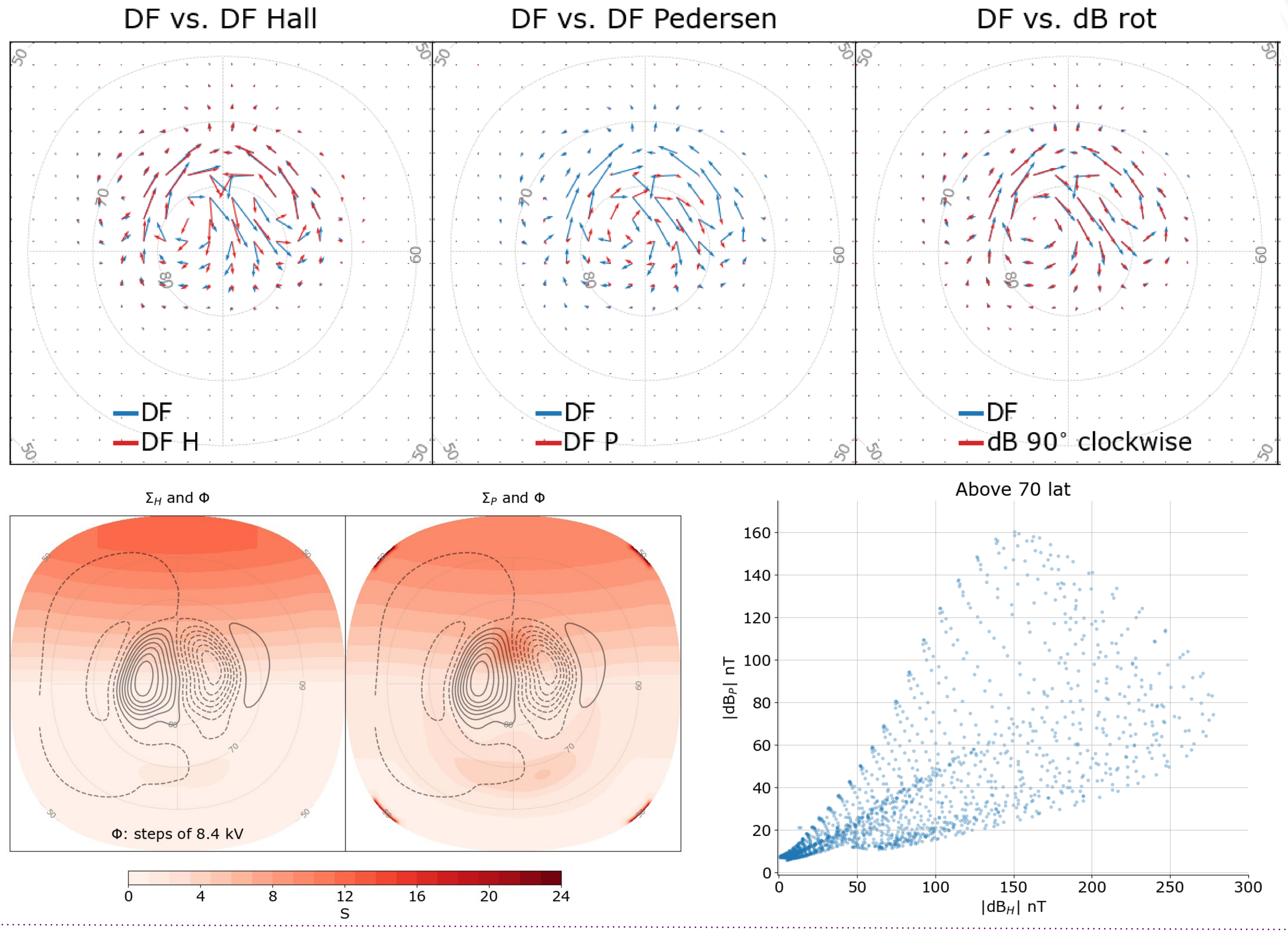
$\boldsymbol{J}_{DF}$ can be expressed in terms of Σ_H and Σ_P. By negating either Σ_H or Σ_P conductance the Hall and Pedersen contribution to $\boldsymbol{J}_{DF}$ can be retrieved.

We showcase two scenarios;

Case 1:



Case 2:



[Chapman 1951] : https://doi.org/10.1007/BF02246814
[Akasofu et al. 1965] : https://doi.org/10.1016/0021-9169(65)90087-5
[Baumjohann et al. 1977] : https://journal.geophysicsjournal.com/JofG/article/download/250/209
[Fukushima 1994] : https://doi.org/10.1029/94JA00102
[Baumjohann 1982] : https://doi.org/10.1016/0273-1177(82)90363-5
[Unitedt and Baumjohann 1993] : https://doi.org/10.1007/BF00750770
Gamera : http://dx.doi.org/10.3847/1538-4365/ab3a4c
OpenGGCM : https://openggcm.sr.unh.edu/?n=Main.HomePage
Lompe : https://doi.org/10.1029/2022JA030356