Using vorticity to characterise meso-scale ionospheric flow variations

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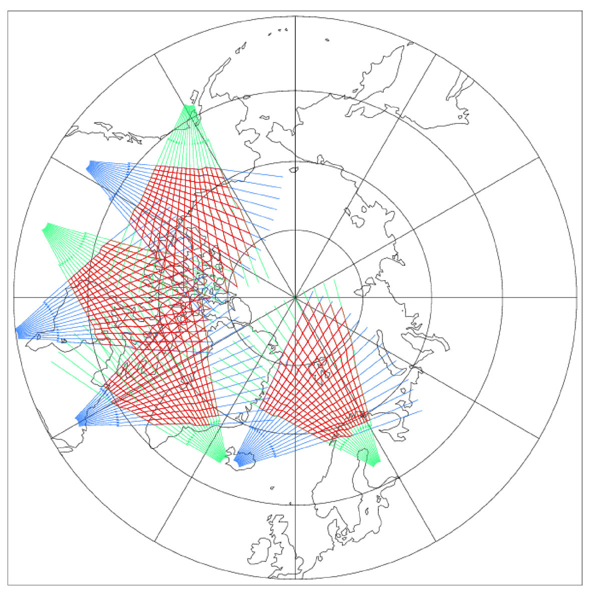
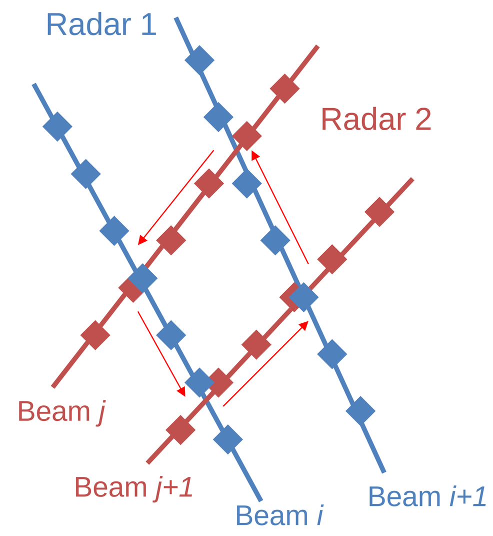




SuperDARN vorticity determination
Uses Stokes' Theorem

$$\oint_C \mathbf{V}.\mathbf{dl} = \int_S (\nabla \times \mathbf{V}).\mathbf{dS}$$

BACKGROUND

(1) The large-scale behaviour of ionospheric plasma flow and its response to driving from the solar wind and magnetosphere are well-known, but the drivers and characteristics of the flow on small and meso-scales is poorly understood. Hence, ionospheric models typically only capture the large-scale behaviour.

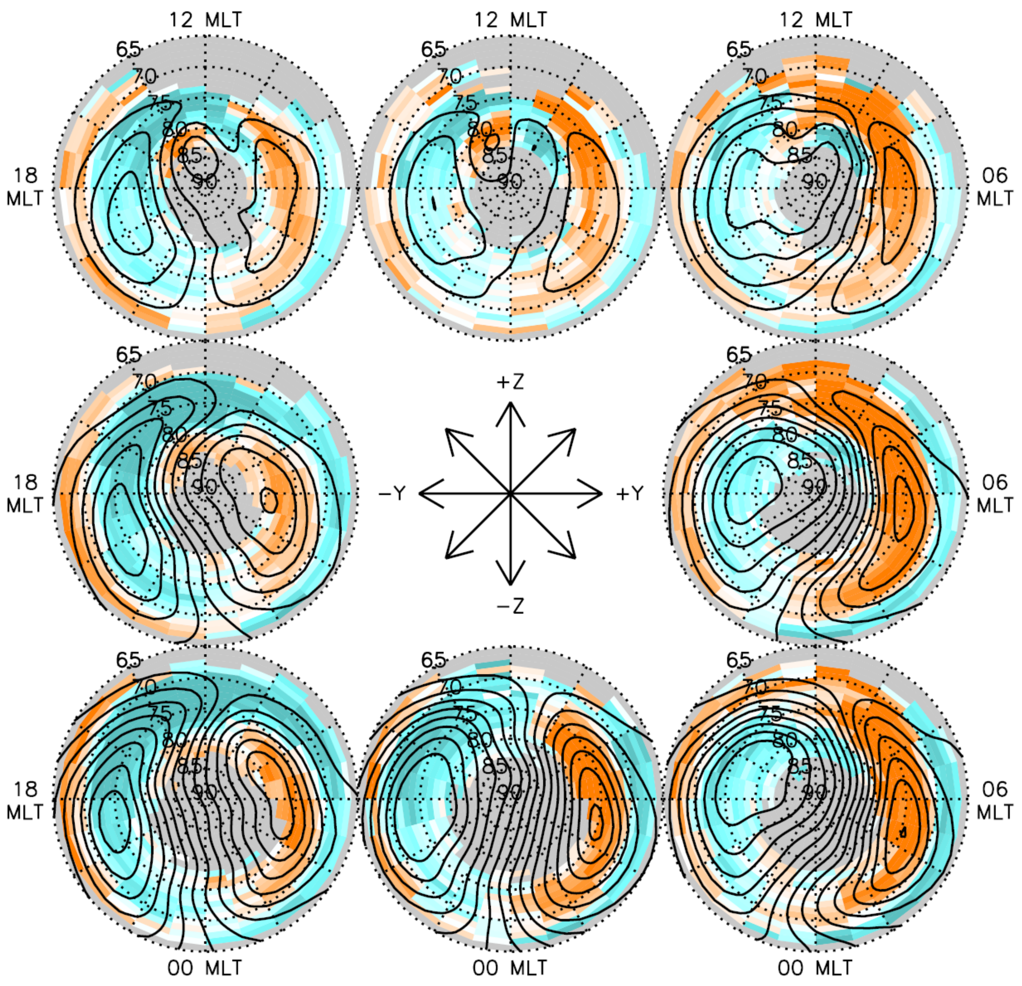
(2) Measurements of ionospheric flow vorticity can be used for studying ionospheric plasma transport processes over a wide range of spatial scales. Here, we present measurements of probability density functions (PDFs) of ionospheric vorticity measured by the Super Dual Auroral Radar Network (SuperDARN), over a six-year interval (2000-2005 inclusive), covering the entirety of the northern hemisphere high-latitude ionosphere.

(3) The vorticity PDFs can be subdivided for different Interplanetary Magnetic Field (IMF) directions, which also allows the separation of the observed PDFs into two distinct components. These components relate to: (1) The large-scale ionospheric convection flow driven by magnetic reconnection; (2) Meso-scale processes such as turbulence.

ANALYSIS METHOD (Chisham and Freeman, 2023)

- Figure 1 shows Thomas and Shepherd (2018) model large-scale convection for different IMF directions.
- Figure 1 shows mean ionospheric vorticity for different IMF directions.
- Mean value is a result of vorticity PDF asymmetry, and not due to a shift in the peak value.
- PDF asymmetry (figure 2) is due to a superposition of vorticity due to large-scale convection and that due to meso-scale processes.

FIGURE 1



- The 'Meso-scale' PDF (black) is broadly symmetric around zero and can be modelled by a q-exponential distribution (Chisham and Freeman, 2010).

$$p_{q,\kappa}(x) = \frac{1}{\kappa}\left(1-\frac{(1-q)x}{\kappa}\right)^{q/(1-q)}$$

- The 'Large-scale' PDF (red) is single-sided and can be modelled by a Weibull distribution (Chisham and Freeman, 2010).

$$p_{c,\chi}(x) = \frac{c}{\chi}\left(\frac{x}{\chi}\right)^{c-1}\exp\left[-\left(\frac{x}{\chi}\right)^{c}\right]$$

Dawn Cell Region 1 – By Positive

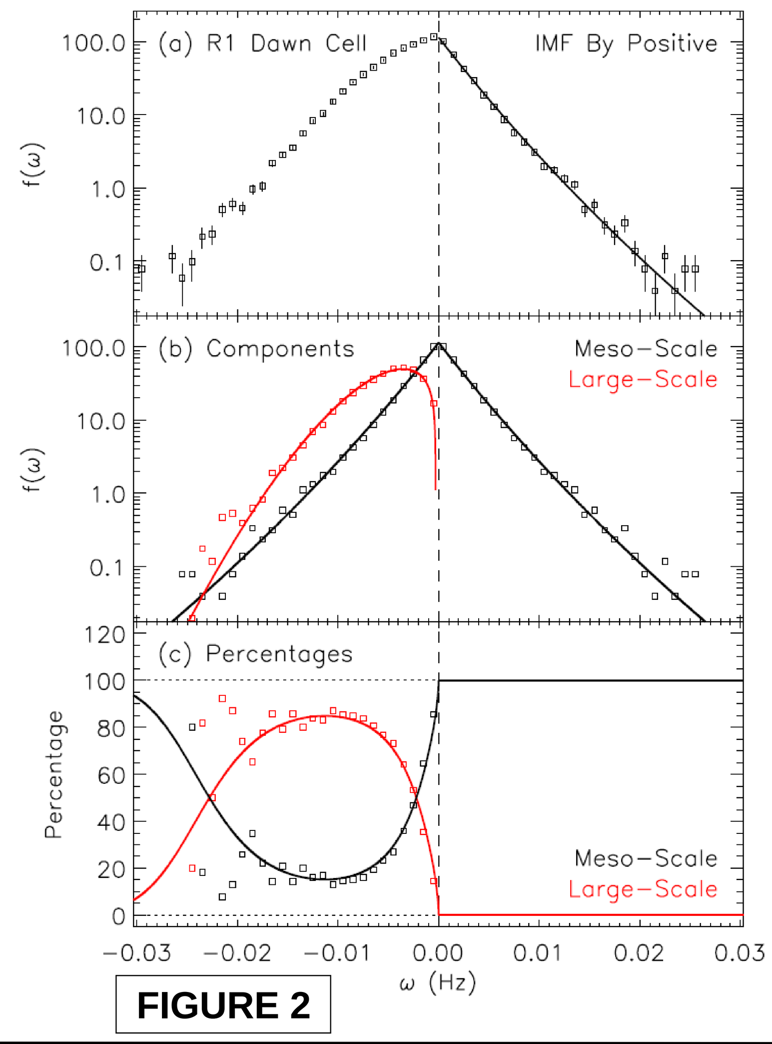


FIGURE 2

RESULTS (Chisham and Freeman, 2024)

- Weibull parameters for large-scale vorticity component.
- Ordered by large-scale flow – dependent on IMF direction.

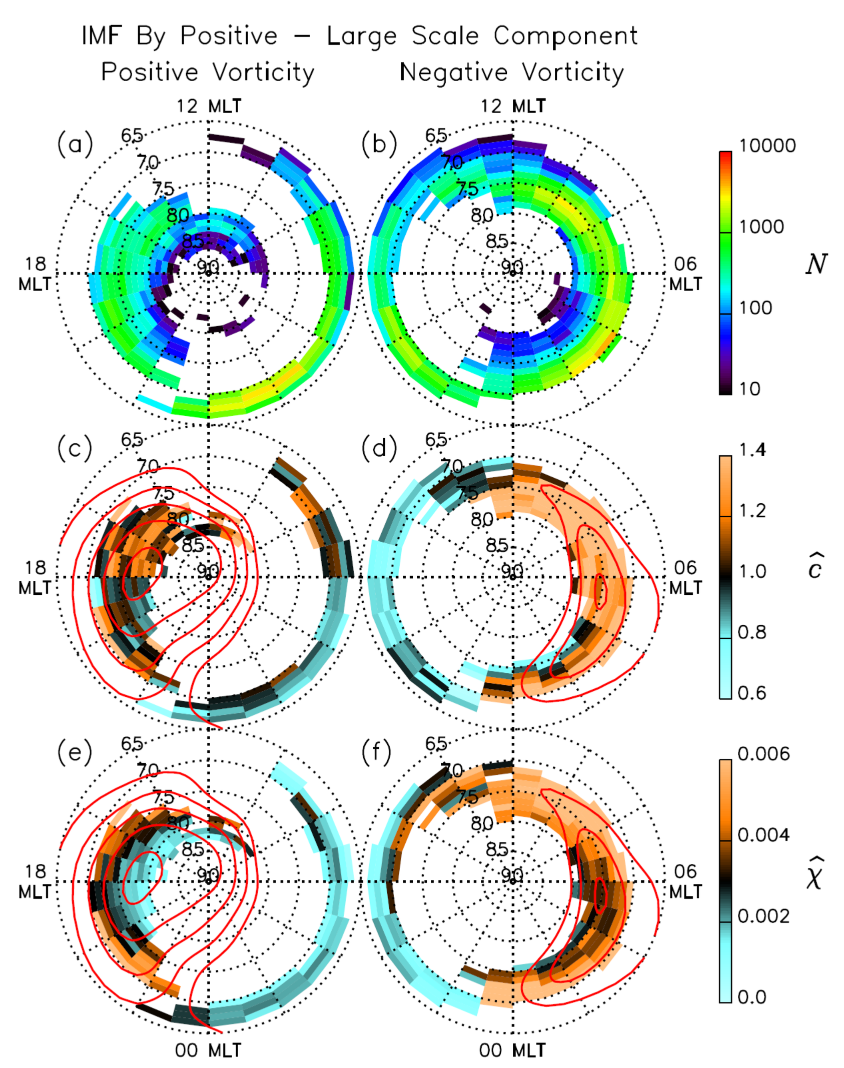


FIGURE 3

- q-exponential parameters for meso-scale vorticity component.
- Independent of vorticity sense.
- Independent of IMF direction.
- Variable with ionospheric location.

FIGURE 4

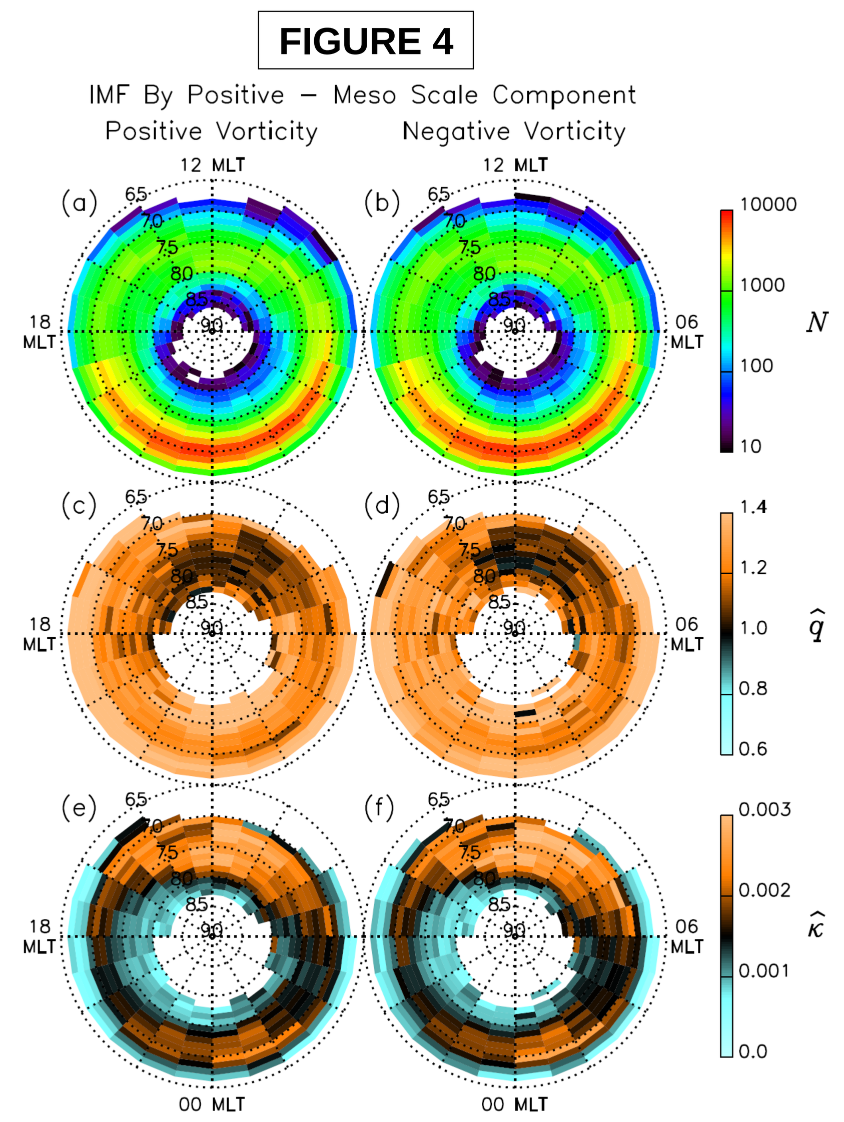


FIGURE 5

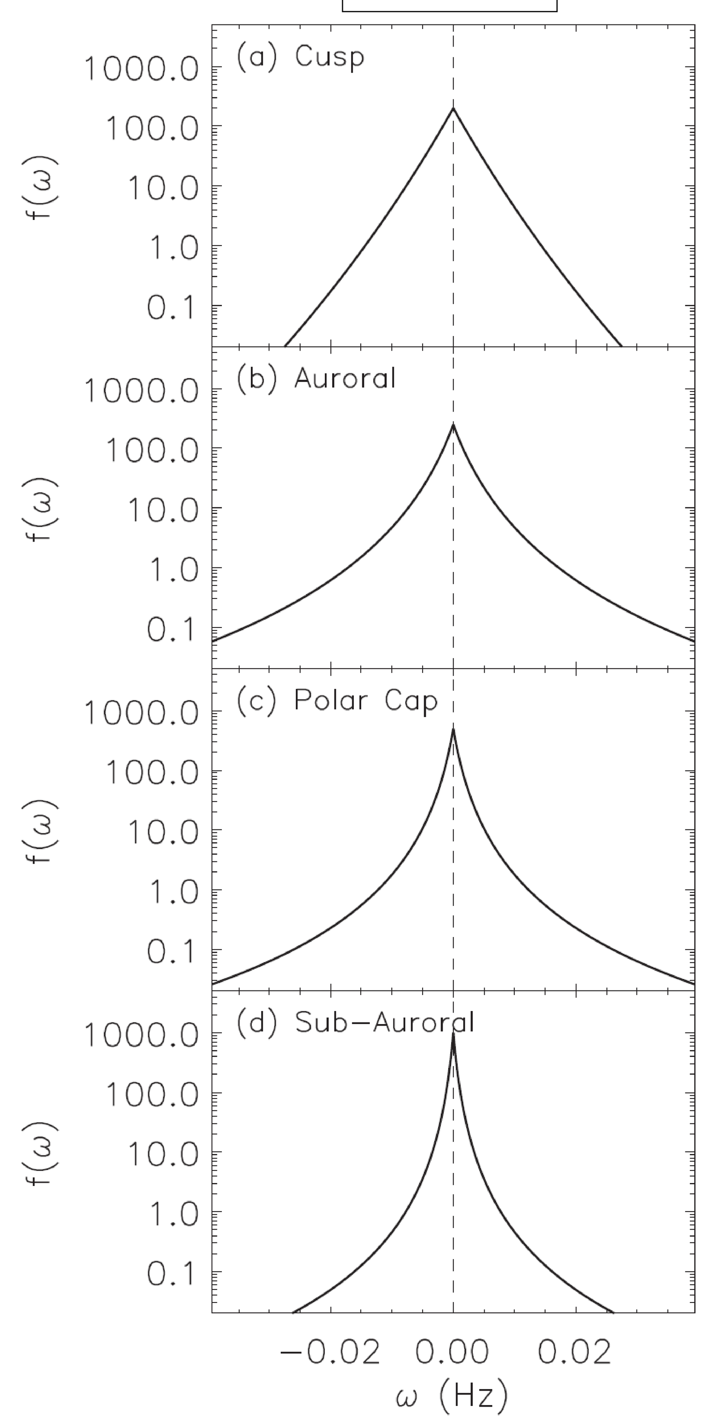
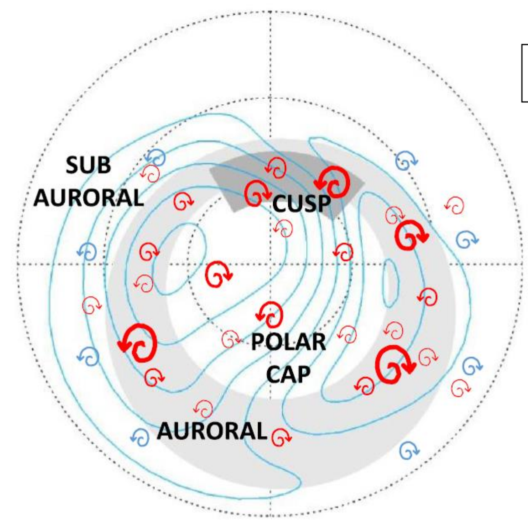


FIGURE 6



- **Cusp** – strongest meso-scale vorticity, most likely driven by transient phenomena associated with solar wind/magnetosphere coupling.
- **Auroral Region** – strong meso-scale vorticity, most likely driven by nightside processes such as substorms, and by turbulent flows associated with flow shears.
- **Polar Cap** – driven by the remnants of meso-scale cusp structure advecting with the large-scale flow, but decreasing in strength with increased intermittency.
- **Sub-Auroral Region** – smallest meso-scale vorticity, but the most intermittent. Driven by fragmented and filamentary region 2 field-aligned currents.

- **IMPACT** – Considering plasma flow due to meso-scale structures will significantly affect ionospheric Joule heating estimates.

SUMMARY/CONCLUSIONS: (1) High-latitude ionospheric vorticity PDFs can be separated into two distinct components relating to large-scale and meso-scale processes. (2) The large-scale vorticity PDFs are single-sided and controlled by the large-scale convection flow. (3) The meso-scale vorticity PDFs are double-sided and symmetric, and are independent of the IMF direction. (4) These PDFs vary systematically with ionospheric location. (5) Future models of ionospheric flow need to consider these meso-scale variations in order to improve estimates of processes such as Joule heating.

Chisham and Freeman (2010) – Geophysical Research Letters, doi:10.1029/2010GL043714
Chisham and Freeman (2023) – JGR Space Physics, doi:10.1029/2023JA031885
Chisham and Freeman (2024) – JGR Space Physics, doi:10.1029/2024JA032887
Thomas and Shepherd (2018) – JGR Space Physics, doi:10.1002/2018JA025280

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