The heavy-tailed distributions of Birkeland currents observed by AMPERE

John Coxon[1]*, Gareth Chisham[2], Mervyn Freeman[2], Brian Anderson[3], Robert Fear[1]

*work@johncoxon.co.uk

1 University of Southampton, 2 British Antarctic Survey, 3 JHU/APL

UNIVERSITY OF Southampton

Science & Technology Facilities Council

Birkeland currents link the magnetopause to the ionosphere

Birkeland currents are the method by which stresses on the magnetosphere are communicated electrodynamically to the ionosphere during phenomena such as geomagnetic storms and substorms. As such, they are a key part of understanding the way in which energy is transferred from space weather phenomena to the atmospheric current systems which cause hazards to technology at the surface.

We use AMPERE to examine the Birkeland currents in this study. AMPERE is a dataset comprising measurements from 66 satellites in LEO and gives Birkeland current densities on a grid of 24 hours in MLT and 50° colatitude, for 1200 coordinates in total.

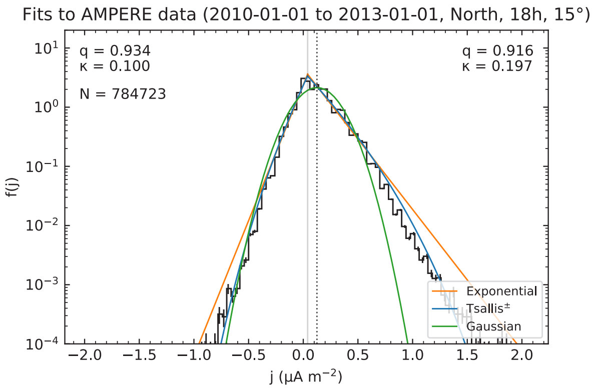
Birkeland currents are distributed in the same way as ionospheric vorticity (below).

We exploit AMPERE's high data density to determine the best parameters for the q-exponential distribution in each coordinate (top right).

We then use this with the survival function to estimate the probability of current density flowing above a given threshold in any given coordinate (bottom right).

Spatial distributions

Chisham et al (2009) showed that ionospheric vorticities could be measured with SuperDARN as a proxy for Birkeland currents, and **Chisham and Freeman (2010)** showed that ionospheric vorticities are distributed leptokurtically (that is, they are heavy-tailed, indicating complexity).



This is also true in Birkeland currents observed by AMPERE (right). The distributions of the currents are clearly not Gaussian (green line) and instead are best described by a q-exponential (blue line).

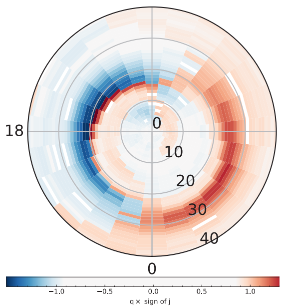
The probability density function (PDF) of a q-exponential

The PDF is a function of q and of κ (see right). Increasing q makes the distribution more heavy-tailed; κ makes it longer-tailed.

$$f(j) = \frac{1}{\kappa}\left(1 - \frac{(1-q)j}{\kappa}\right)^{q/(1-q)}$$

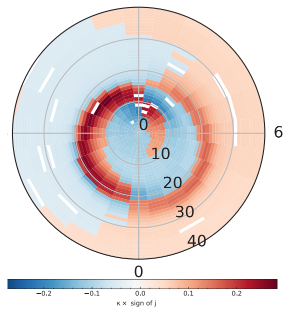
Fitting q-exponential distributions to the data

We use maximum likelihood estimation to determine the q-exponential function which best fits the data, and we show the results of this in each coordinate below.

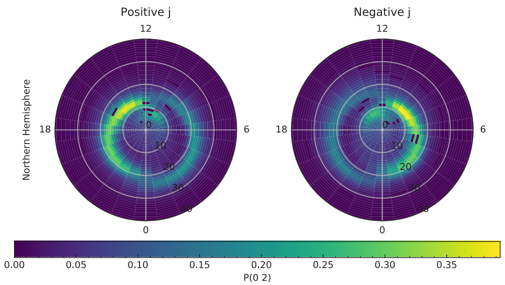


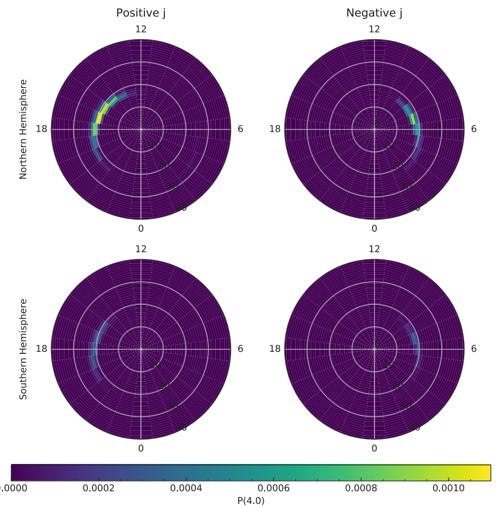
We plot the q parameter of the best fit in each coordinate (left) and the κ component of the best fit in each coordinate (right) for the currents above the mode current in the Northern Hemisphere. In both panels we multiply by the sign of the mean current density in that coordinate.

We find that R1 current is associated with high κ and R2 with high q.



Probabilities of current density above some threshold





Left: 0.2μA m^{-2}: the approximate noise level of AMPERE (Anderson et al., 2014). The maximum probability at this threshold is ~40%, and R1 is more likely than R0/R2.

Right: 4 μA m^{-2}, which is an extremely high current density. This is much less likely (~0.1%) and only seen on the dayside, near colatitudes of 20° and not near noon.

Probabilities are higher in the Northern Hemisphere than the Southern Hemisphere.