British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Near real-time characterisation of auroral activity using satellite magnetic data

Brian Hamilton [bham@bgs.ac.uk]
British Geological Survey, West Mains Road, Edinburgh, United Kingdom

Introduction

In the auroral regions, magnetic disturbances can reach hundreds of nanotesla. These are caused by ionospheric currents coupled with the magnetopsphere (Fig. 1a) that are strongly influenced by interactions with the solar wind and are therefore difficult to predict. The ability to characterise these disturbances in near real-time is of scientific interest, and could have practical benefits for high-latitude users of magnetic referencing and for power grids susceptible to geomagnetically induced currents. Presently, there are some (near) real-time auroral activity products that are derived from various ground and satellite data, often in combination with empirical models, e.g. NOAA's Auroral Activity and Ovation Forecasts, and the CSSDP's Real-Time Auroral Oval. However, no near real-time models of ionospheric current systems directly derived from satellite magnetic data have been created. Therefore, we assess the feasibility of automated near real-time characterisation of auroral activity based on satellite magnetic measurements.

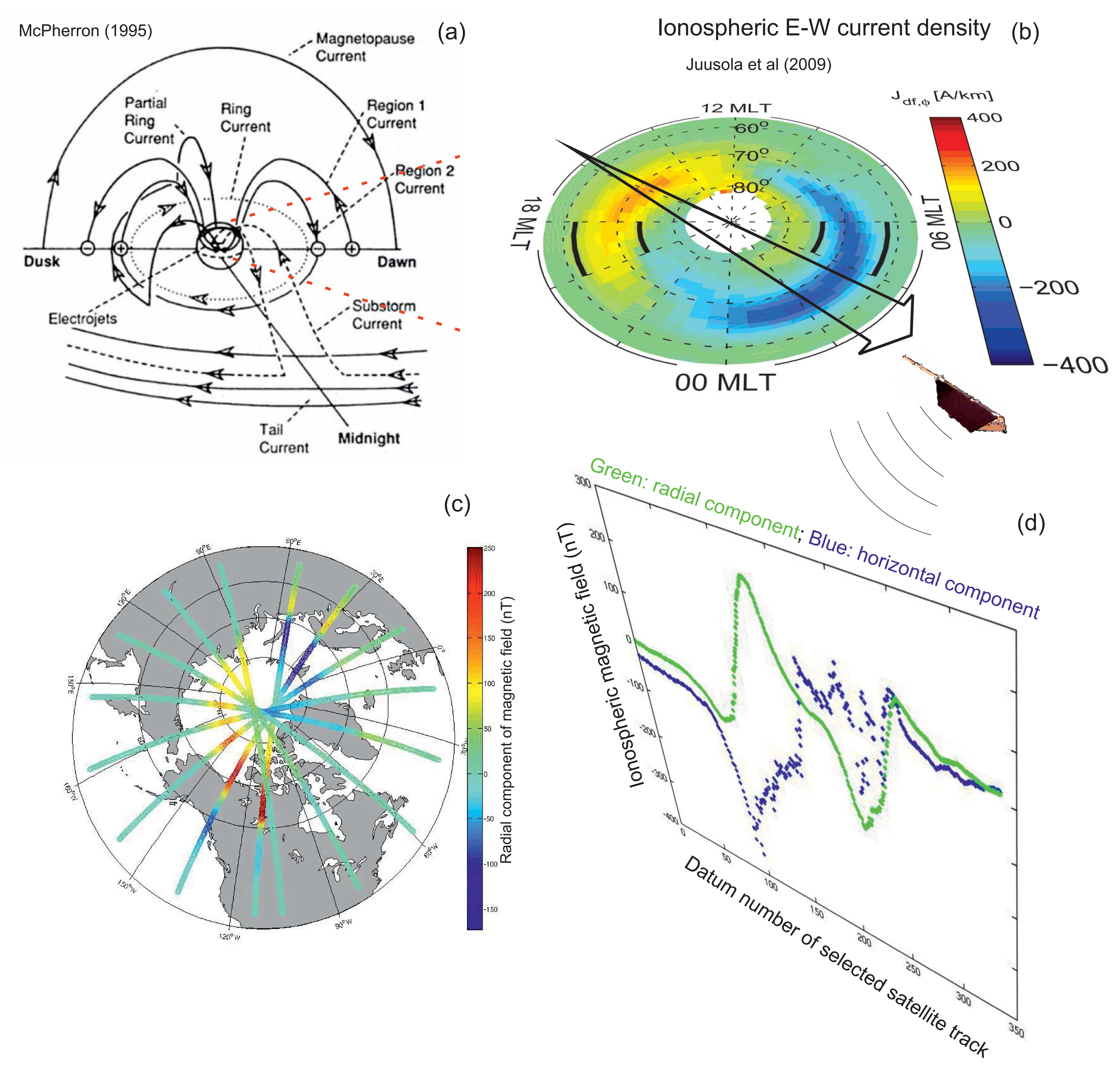

Figure 1: (a) electrical currents in the ionospheric-magnetospheric system [1]; (b) map of east-west currents from CHAMP satellite data [2] showing orbit local time selected for our analysis to best sample the east-west currents; (c,d) sample of ionospheric field data isolated in our analysis from several orbits (c) and a single track (d). Note that the geographic coverage in (c) is due to Earth rotation, data is from a narrow range of local times (14-17hrs & 02-05hrs).

Automated processing

We tested our code on a small sample of CHAMP data from July 2005, when the satellite orbits are in a favourable range of local-times (14-17hrs/02-05hrs) for detecting E-W currents (Fig 1b). Models of the core and lithospheric magnetic fields were removed to isolate ionospheric and magnetospheric sources. We then used code developed by BGS for the ESA Swarm satellite mission [3,4] to estimate and remove the large scale magnetospheric field for each orbit to leave the residual ionospheric fields (Fig 1c,d). The data were then separated into northern and southern hemisphere subsets. CHAMP was a low altitude satellite with an orbit period of ~90 minutes and so alternates between sampling the northern and southern auroral regions every 45 minutes. These data sets are then used to produce an Auroral-Electroject like index (Fig 2) and to estimate the location of the eastward- and westward-directed current systems (Fig 3), as seen by CHAMP at approx. 400 km altitude. Processing one month of data takes a couple of hours on a modestly powered desktop machine, although this could be optimized further.

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[2] Juusola, L., Kauristie, K., and Ritter, P., 2009. Statistical dependence of auroral ionospheric currents on solar wind and geomagentic parameters from 5 years of CHAMP satellite data, Annales Geophysicae, 27, 1005-1017.
[3] Friis-Christensen, E., Luhr, H., and Hulot, G., 2006, Swarm: A constellation to study the Earth's magnetic field, Earth Planet Space, 58, 351-358.
[4] Hamilton, B., submitted, A rapid model of the large-scale magnetospheric field from Swarm satellite data, Earth Planets Space.
[5] Menvielle, M., Iyemori, T., Marchaudon, A., and Nose, M., 2011, Chapter 8: Geomagnetic Indices, In: Geomagnetic Observations and Models, Springer, 183-228.
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[7] Wills, A., 2010, Quadratic Programming in C, downloaded from: http://sigpromu.org/quadprog/.

Satellite based Auroral Electrojet Index

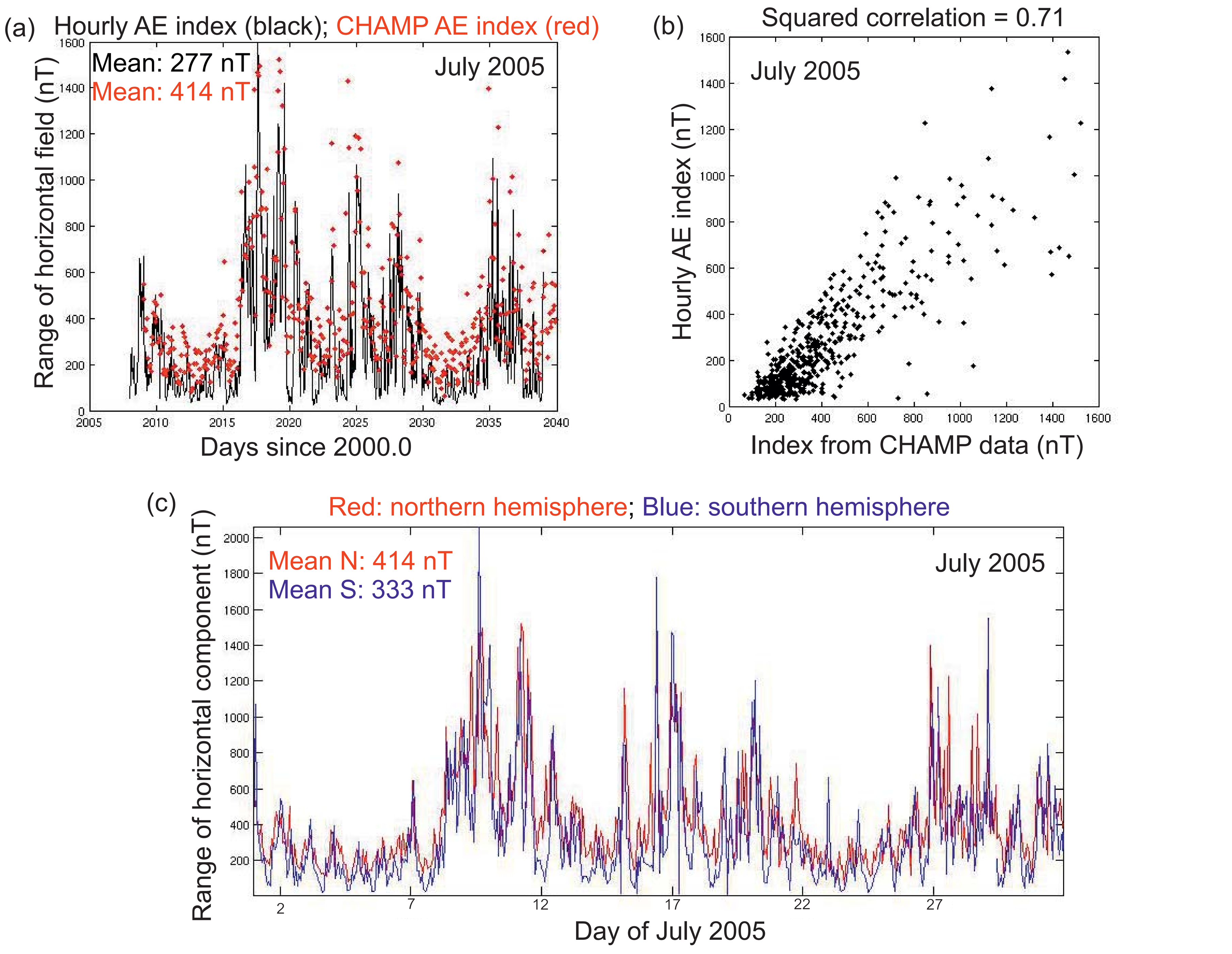

Figure 2: (a,b) comparison of AE and equivalent index produced from CHAMP July 2005 data presented as (a) a time-series and (b) a correlation plot. (c) Comparison between CHAMP equivalent AE index from northern and souther polar crossings.

Fig 2(a,b) shows a comparison between the hourly version of the Auroral-Electrojet (AE) Index based on the range of the horizontal component of the field from 12 high-latitude observatories [5] and an analogous index produced by our code from the horizontal component of the processed CHAMP data (e.g. Fig 1d, blue curve). Fig 2(a,b) shows a reasonable correlation between the two indices, although there is over 100 nT difference between their mean values. This could be a result of the different altitudes of observatories and CHAMP but may also be influenced by our extraction of ionospheric signals using magnetic field models rather than the local baselines for each observatory. Fig 2(c) demonstrates an obvious advantage of using satellite data: coverage of both northern and southern hemispheres. Both hemispheres' indices follow each other closely but there is a difference in their mean values most likely due to seasonal effects. Although the time-resolution of the CHAMP index is far lower that the 1 minute AE index and the local-time coverage is narrower this could be improved by the upcoming ESA Swarm three-satellite mission. Furthermore, satellite data could help overcome some of the limitations on the fixed-observatory AE index [5] since they are sampled at high resolution in latitude; are not vulnerable to man-made interference; and are sufficient to co-estimate a magntospheric model to isolate the ionospheric fields.

Locating the auroral current systems

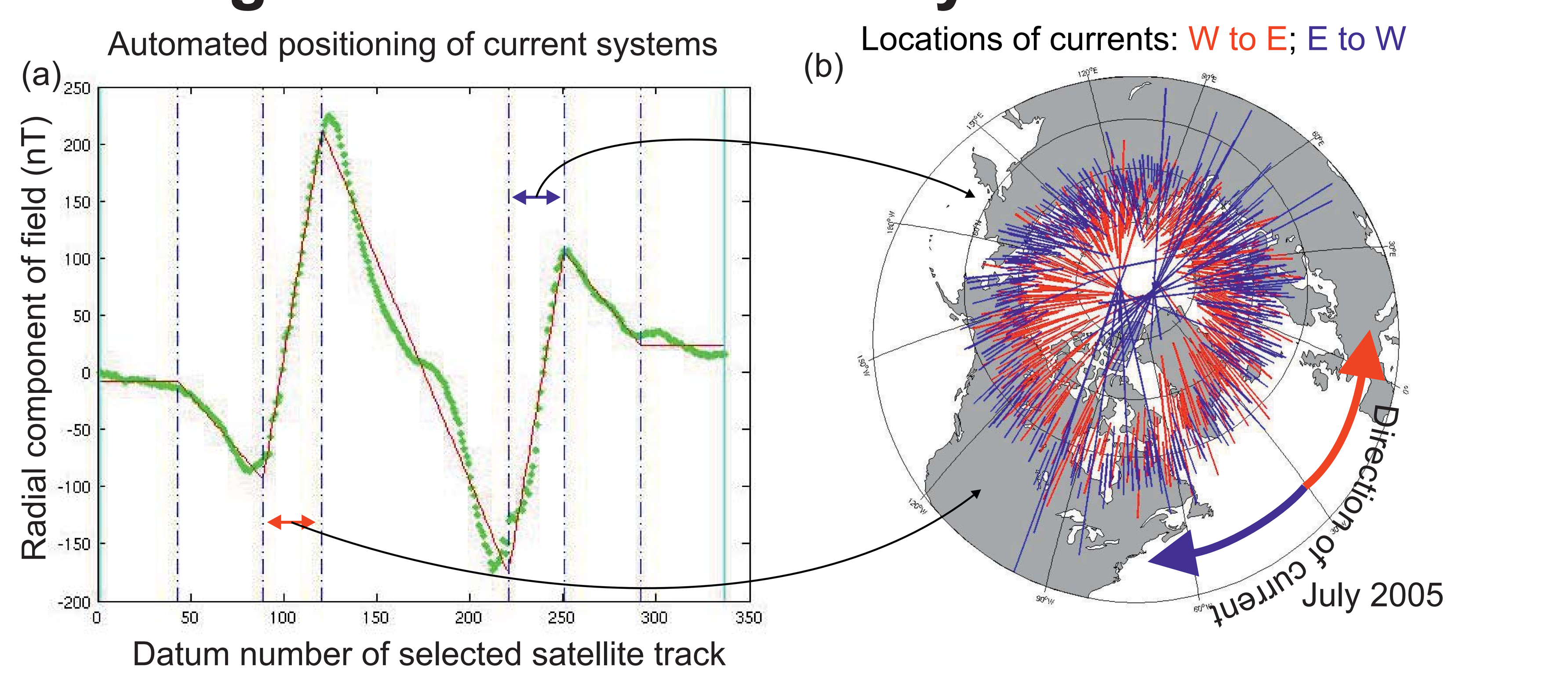

Figure 3: (a) an example of a least squares piecewise-linear fit of constrained shape (red line) to the radial ionospheric field (green). (b) Applied to July 2005 data, linear segments can then be interpreted as the approx. loci of eastward and westward currents. Note the geographic coverage is due to Earth rotation as the satellite data are from a narrow range of local-times (14-17hrs & 02-05hrs).

Finally, we try a simple scheme to automatically identify the auroral oval using satellite data and spline-fitting code [6,7] that allows free knot-positions but constrains the gradient of each interval (Fig 3). The expected shape is roughly fit in 69% of northern passes (Fig 3b) but only 37% in the south. This is probably due to the southern dip-pole being located further from the sampling path of the satellite's polar orbit. This may be improved by Swarm but a more robust method, possibly based on comparisons with statistical models of the current systems [2], such as that shown in Fig 3(b) may be required.