Boston University Center for Space physics

Energy Flux Maps of Precipitating Electrons using Poker Flat Incoherent Scatter Radar

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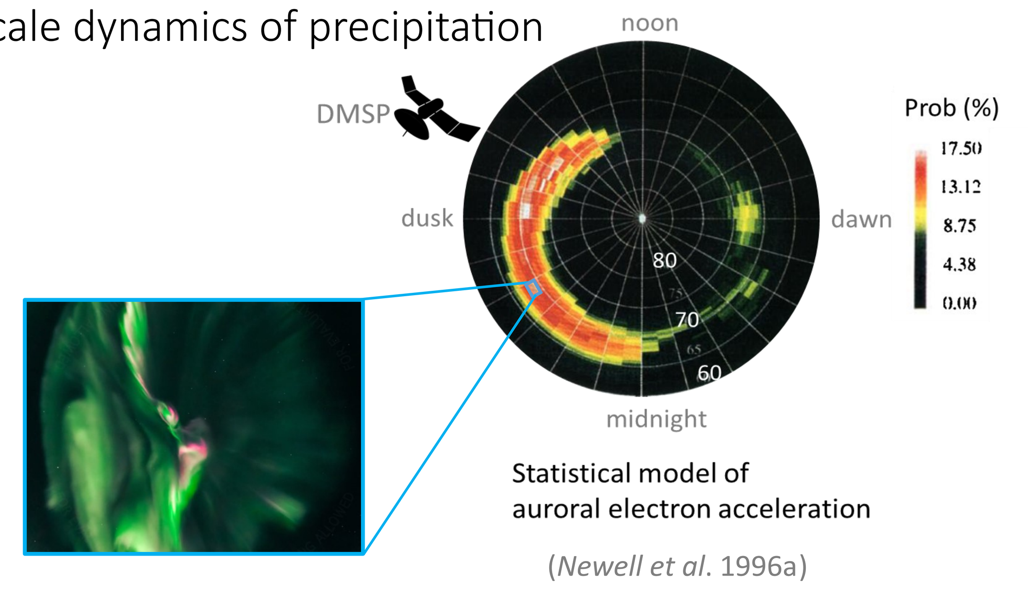
Abstract

Energetic particle precipitation can cause enhanced conductivity structures that affect current flow in the ionosphere, which in turn can affect magnetospheric convection. Global precipitation models are therefore essential in understanding magnetosphere-ionosphere coupling. However, existing precipitation models are statistical and they do not capture small-scale structural and temporal variations. This drawback hampers accurate modelling of the magnetosphere-ionosphere dynamics during substorms. In order to study small-scale variations we need quantitative and continuous multi-point measurements of particle precipitation. For this reason, we have developed a novel technique to estimate energy flux maps of precipitating electrons spanning latitude, longitude, time and energy. The technique inverts electron density measurements from Poker Flat Incoherent Scatter Radar to estimate the primary electron energy flux that caused the ionization. Here we demonstrate the ability of energy flux maps to identify precipitation structures during a large substorm on 26th March 2008. Our observations during the growth phase of the substorm show a clear precipitation of high energy electrons ~ 100 keV associated with the stable trapping boundary. Unlike in-situ and single point measurements, this technique offers continuous diagnostics of precipitating electrons with a spatial coverage of ~50x50 km. The ability to quantitatively observe spatial structure and time evolution of energetic precipitation is new, and promises to advance our understanding of magnetosphere-ionosphere coupling.

Motivation

Global models of precipitation do not capture small scale dynamics of precipitation



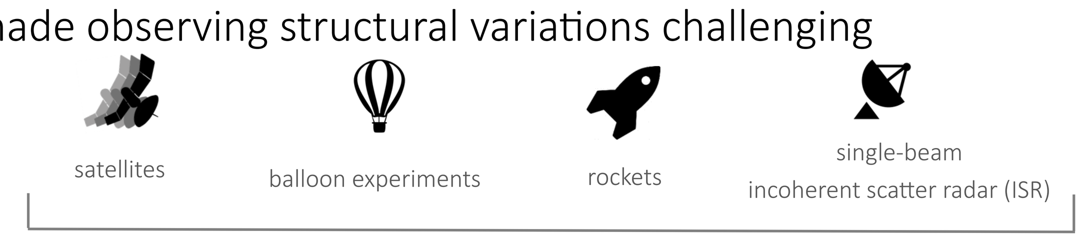
Statistical model of auroral electron acceleration

(*Newell et al.* 1996a)

Since global precipitation models do not capture small-scale dynamics, global conductivity models that are derived from them also do not.

Conductivity models are essential in modelling magnetosphere-ionosphere coupling. The limitations of current models impede our ability to accurately predict substorm dynamics.

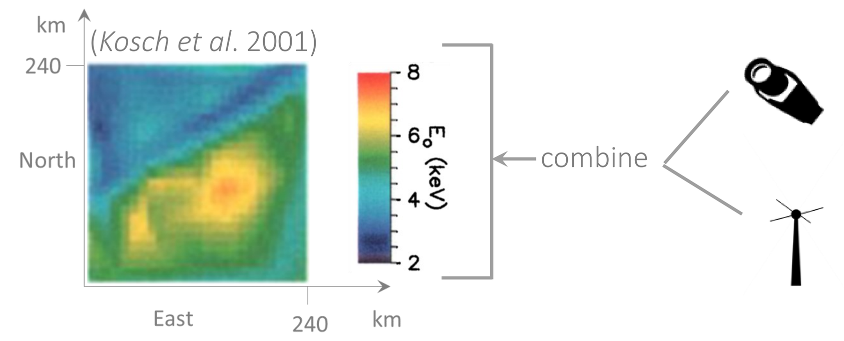
Lack of instruments with spatial coverage has made observing structural variations challenging



these independently provide **no spatial coverage**

First small-scale structure of precipitation estimated using characteristic energy maps

(*Kosch et al.* 2001)



Optical multi-wavelength measurements From **digital all-sky camera** estimates <15 keV

Auroral absorption images from **2-D imaging riometer** estimates > 25 keV

However, characteristic energy maps **cannot estimate energy flux**, and has **poor energy coverage**.

Solution: Energy flux maps to study small-scale structure of precipitation.

Findings

Fig.2 100 keV electron precipitation moving equatorward during substorm growth phase

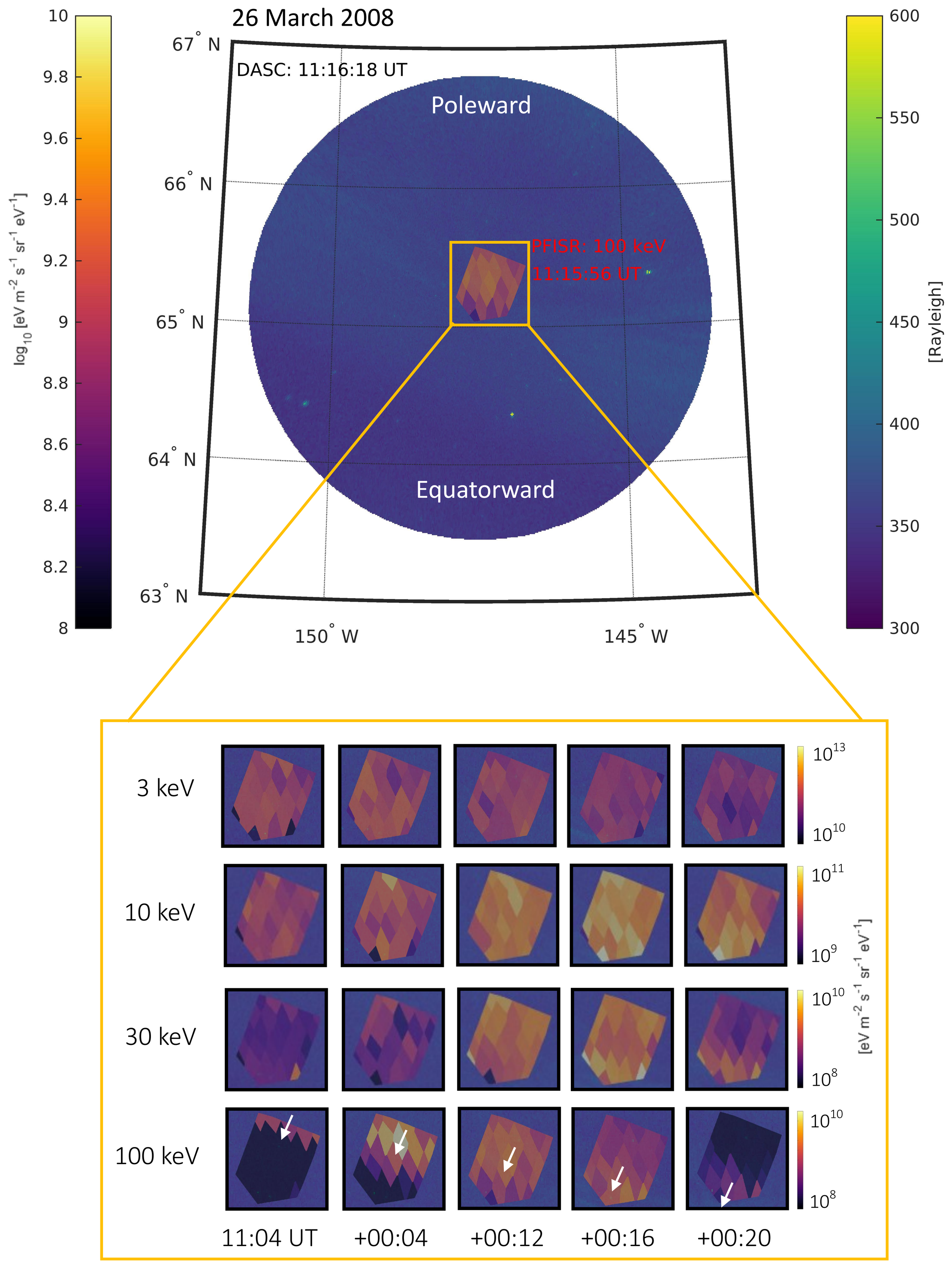


Fig.2 The slices of energy-flux-maps in time are uniquely pertinent for the study of structural variations between different energy regimes not visible in the auroral images.

3 keV :	Mostly uniform spatial distribution, with decreasing flux in time.
10-30 keV :	Mostly uniform spatial distribution, with an increase in flux 12-16 minutes into the growth phase coincident with the diffuse aurora.
100 keV :	A narrow east-west band of 100 keV electron flux drifting equatorward across the PFISR field of view ~ 100 km in about 20 minutes, uncorrelated with lower energy ranges.

Fig.1 3 keV electron energy flux coincides with optical auroral emissions as expected

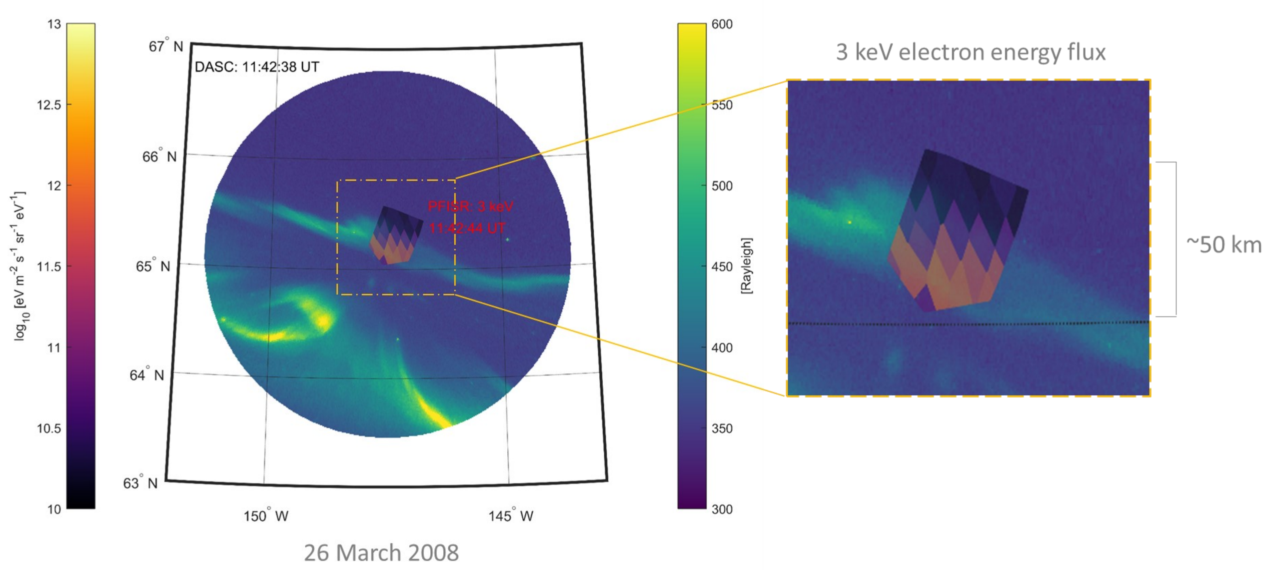
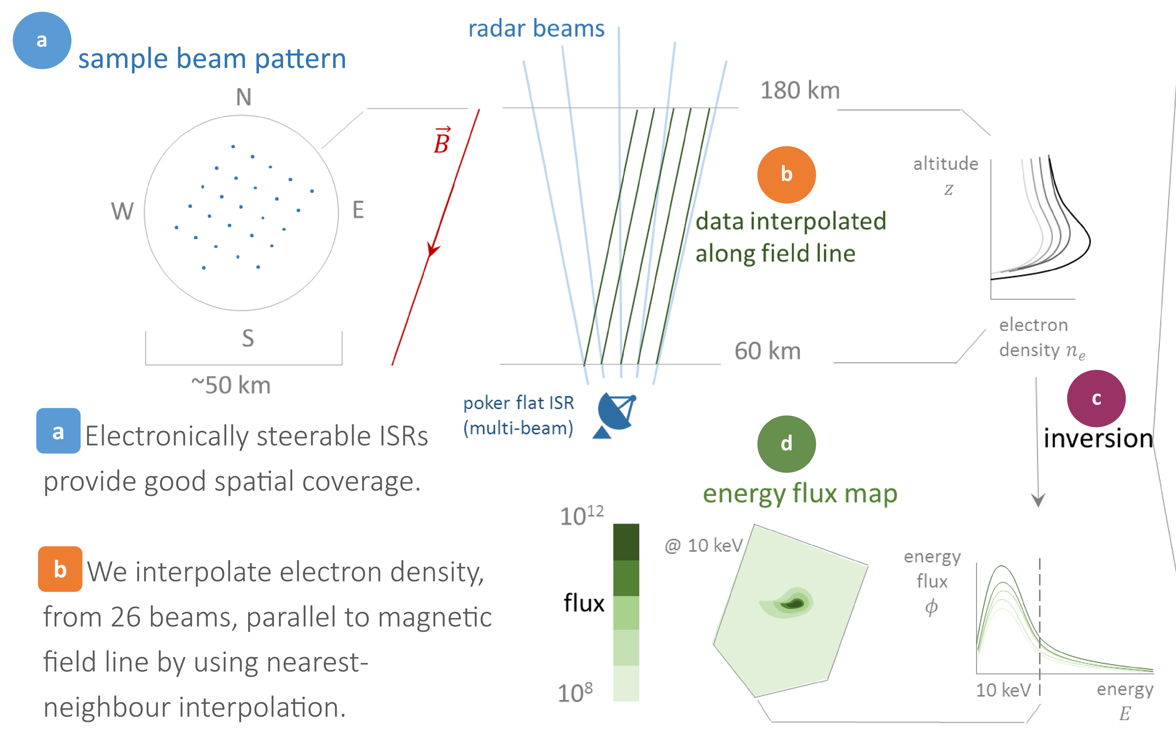


Fig.1 Here the energy flux map of 3 keV electrons is overlaid on a digital all-sky camera (DASC) image of the pre-onset aurora. There is clear overlap of the auroral arc with 3 keV electron precipitation. This is in agreement with previous observations that most of the auroral luminosity is produced by electrons between 1-10 keV.

Methodology

Poker Flat ISR's multi-beam mode was used to produce energy flux



Step 1. Continuity Equation

$$q(z) = \frac{dn_e(z)}{dt} + \alpha_{eff} n_e(z)^2$$

production rate; effective recombination rate (ion chemistry model)

Step 2. Forward Model

$$q(z) = [A]\,\phi(E)$$

monte-carlo model of precipitation (Sergienko and Ivanov 1993)

Step 3. Maximum Entropy Method (MEM) Inversion

$$\phi(E) = inv[A]\,q(z)$$

(Semeter et al., 2005)

a Electronically steerable ISRs provide good spatial coverage.

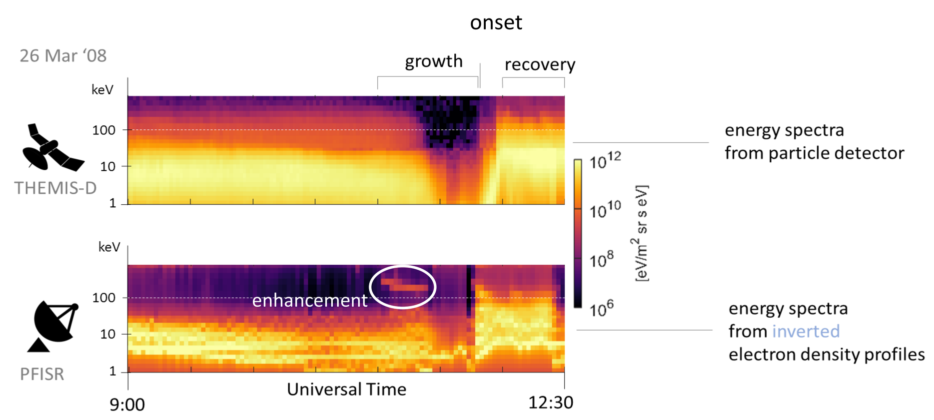
b We interpolate electron density, from 26 beams, parallel to magnetic field line by using nearest-neighbour interpolation.

c We estimate energy spectra from electron density profiles using maximum entropy inversion of the forward model.

d The inversion generates a 4-D data structure with an energy flux value associated with a latitude, longitude, energy and time. From this, we generate an energy flux map — a 2-D slice of differential energy flux of electrons.

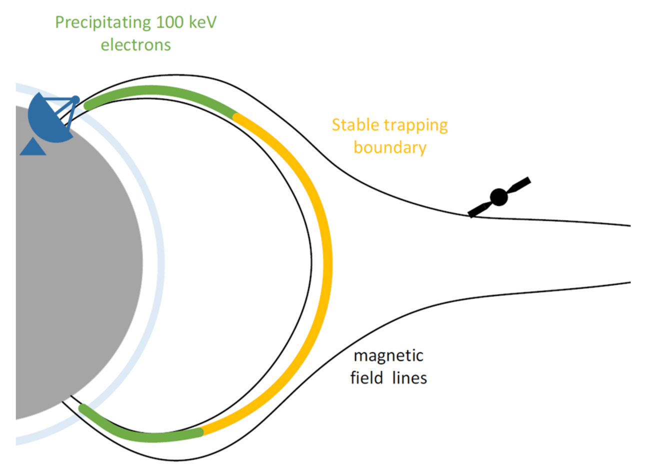
Discussion

>100 keV electron enhancement observed in ionosphere, while not in plasma sheet



The top panel displays energy spectra measured by THEMIS-D in the plasma sheet, and the bottom panel displays the estimated energy spectra of precipitation averaged across all the PFISR beams. The presence of enhancement in the PFISR measurement during the growth phase suggest that the source is likely earthward of THEMIS-D . Conjugate measurements with NOAA-17 spacecraft at low earth orbit (not shown here) excluded high energy proton precipitation (~ 1 MeV) as the source.

Source: Trapped particles scattered as magnetic field stretches



As the source is earthward of the plasma sheet, it is likely the scattering of ~100 keV electrons from the stable trapping boundary at the outer-edge of the radiation belt. This is can be caused by a decrease in the radius of field line curvature in the equatorial plane during the thinning of the plasmasheet.

Conclusion

Key Findings

- Electronically steerable ISR measurements can be used to estimate energy flux maps of precipitating electrons in detail
- Energy flux maps were verified with simultaneous white-light images of the sky
- In a case study of a large substorm, we observed precipitation of energetic electrons greater than 100 keV from the stable trapping boundary during the growth phase
- Energy flux maps developed using ISR are a powerful tool to study small-scale structures of precipitating electrons with nearly continuous coverage and high energy-resolution.

Future Work

- Determine magnetospheric boundaries from the ground, for the first time, using a quantitative scheme to classify precipitation based on their energy spectra (*Newell et al.*, 1996b).
- In order to dispel ambiguity in distinguishing proton and electron precipitation, we plan to use H-β emissions from meridional scanning photometers

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