Multi-event Analysis of Growth-Phase Energetic Electron Precipitation

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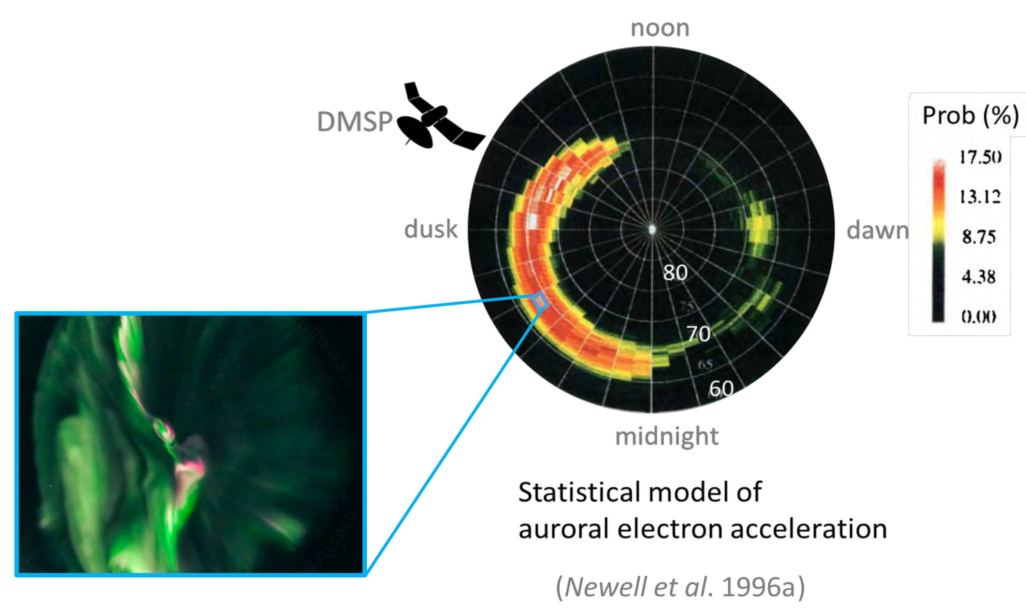
Abstract

Recent studies have shown evidence of energetic electron precipitation (>30 keV) during growth-phase of substorms. Energetic electron precipitation has mostly been observed during substorm expansion and recovery phases. In this work, we examine several substorm growth-phases with Poker Flat Incoherent Scatter Radar (PFISR) in multi-beam modes combined with optical images. This allows us to study the small-scale structure, the relative position to optical aurora, and quantitatively estimate the energy spectra of growth-phase energetic precipitation (GEEP). GEEPs are a latitudinal band of electron precipitation up to ~100 keV observed equatorward of a growth-phase arc. Through this study we aim to narrow down on its source, and analyze its contribution towards charged-particle loss rates in the magnetosphere.

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.

The source and mechanisms related to Growth Phase Energetic Electron Precipitation (GEEP) is unknown

What we know:

- Pytte et al. (1976) was among the first to note the high-energy electron precipitation associated with arcs during the growth phase using bremsstrahlung X-rays from balloon flights and riometer recordings.
- GEEP occurs between the diffuse emission region and bright growth-phase arc, and equatorward of the arc. Their source is speculated to be chorus wave interactions. GEEPs have been observed in conjunction with pulsating aurora during growth phase, and their sources may be connected. (McKay et al. 2018)

What we don't know:

- Small scale structure
- Quantitative estimates of the energy spectra of GEEP
- Its role in loss of energetic particles from the magnetosphere
- Its effects on ionospheric conductivity before the substorm onset
- Plausible links with pulsating aurora
- Differences between growth-phase and recovery-phase EEPs

Solution: Multi-event analysis of GEEP using 2D energy flux maps to study their small-scale structure

Findings

Validation of our energy flux estimates of precipitating electrons: 3 keV electron energy flux coincides with optical aurora as expected

Fig. 1

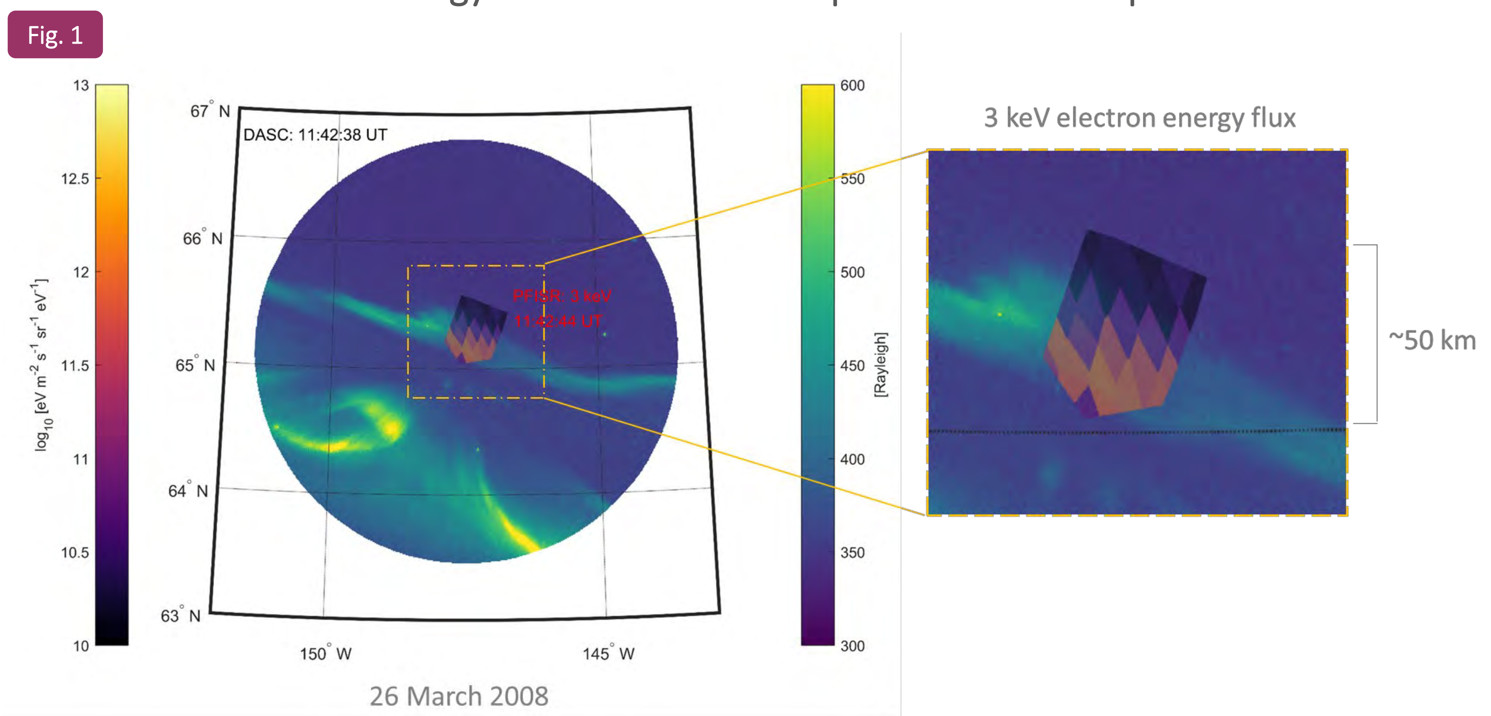
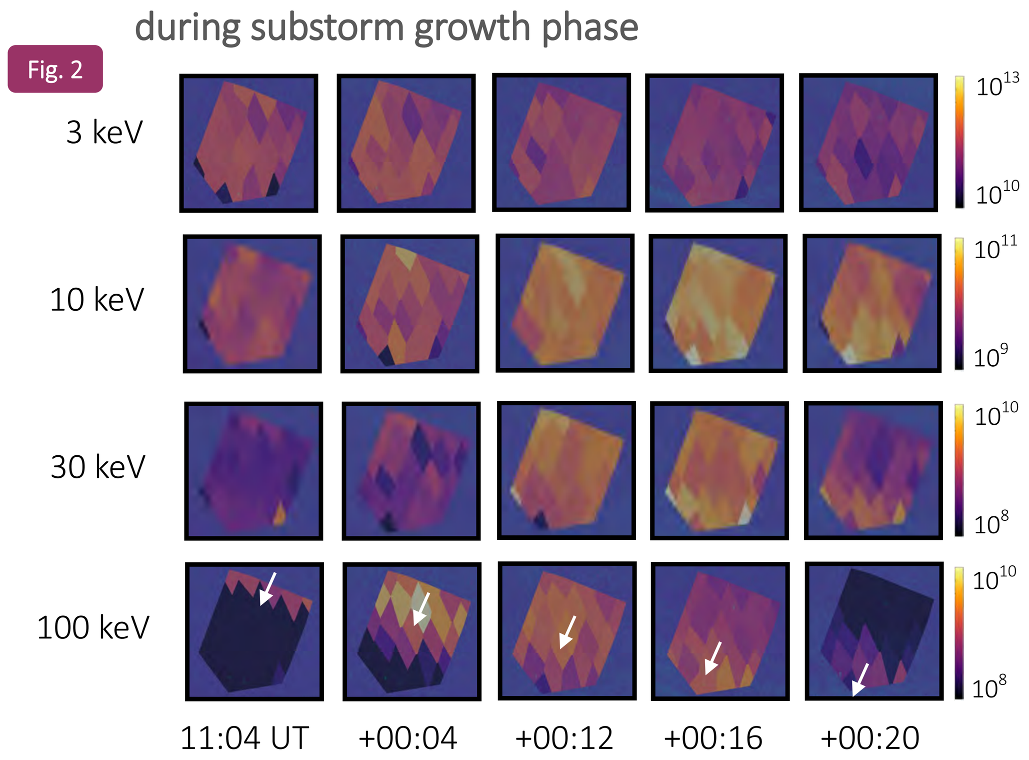


Fig 1. Here the energy flux map of 3 keV electrons is overlaid on a digital all-sky camera (DASC) image of the pre-onset aurora. There is clear overlap of the auroral arc with 3 keV electron precipitation. This is in agreement with previous observations that most of the auroral luminosity is produced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

100 keV electron precipitation moving equatorward during substorm growth phase

Fig. 2



During the growth phase of a substorm on 26 Mar 2008 from 11:00 to 11:40 UT, the growth phase arc passed through the PFISR field of view. Equatorward of the growth phase arc, in the diffuse aurora, a narrow east-west band of energetic electrons ~100 keV is found moving equatorward. This band is what we call the Growth-phase Electron Energetic Precipitation (GEEP), and has been observed during other substorms.

Fig. 3 D-region ionization caused by GEEPs during 3 substorms

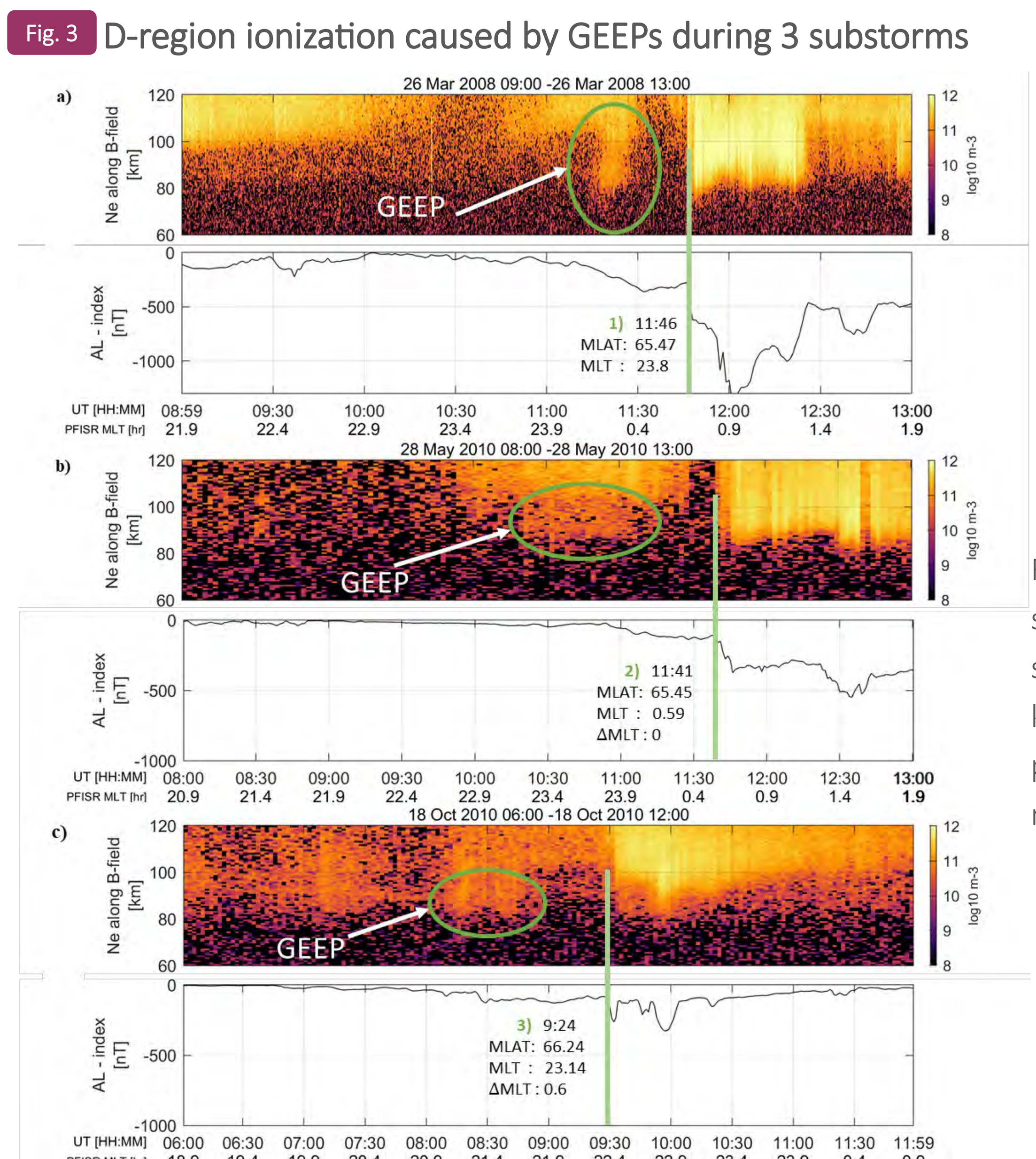


Fig 3. Above are three observations of GEEPs before substorms onsets that have energetic electron precipitation ionizing altitudes as low as 75 km. The gap in ionization between the GEEP and the onset corresponds to regions in the magnetic lobes outside the plasma sheet. From fig 2, the width of the GEEP seems to be ~10-20 km, and time duration of observation ought to depend on the transit time of the growth-phase arc.

Energy spectra of GEEPs for different substorms

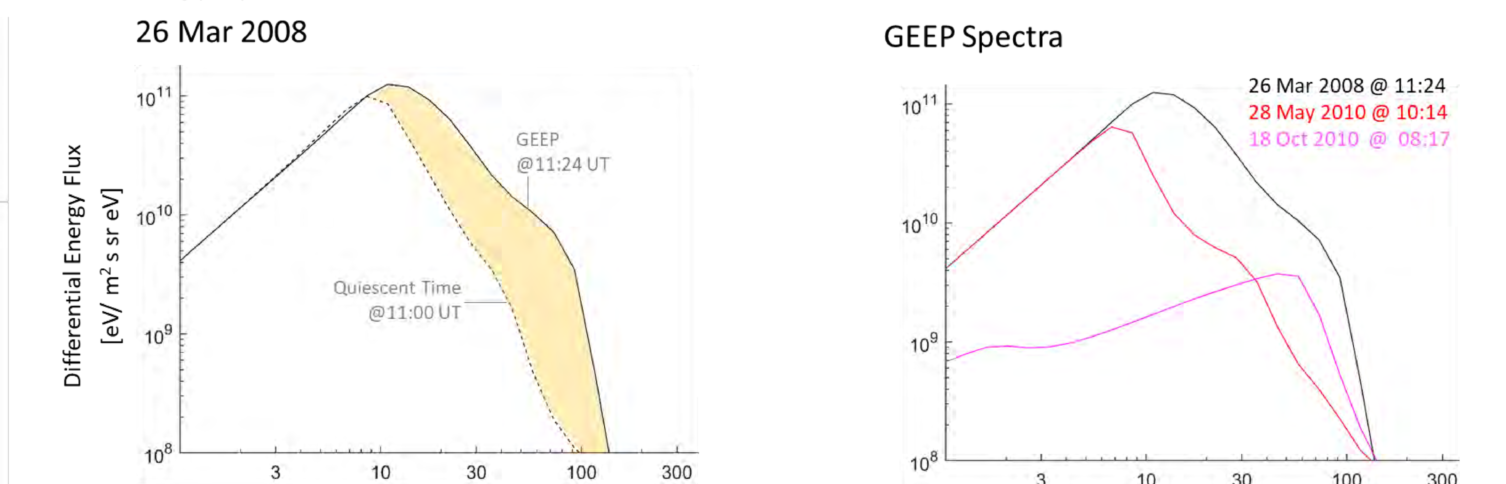


Fig 4. a) Energy spectra of GEEP from 26 Mar 2008 compared with a time before the population is observed (quiescent time). There is a substantial increase in the tail-end of the energy spectra with respect to the quiescent time. b) The GEEP spectra from different events all have a harder spectra, with a knee between 30 -100 keV. On 18 Oct 2010 event (magenta line) we observe energy spectra that is predominantly energetic unaccompanied by low energy electrons < 10 keV. This suggests that the mechanism generating the GEEP may be different from <10 keV precipitation.

GEEPs are observed if the substorm onset occurs near PFISR MLAT & MLT

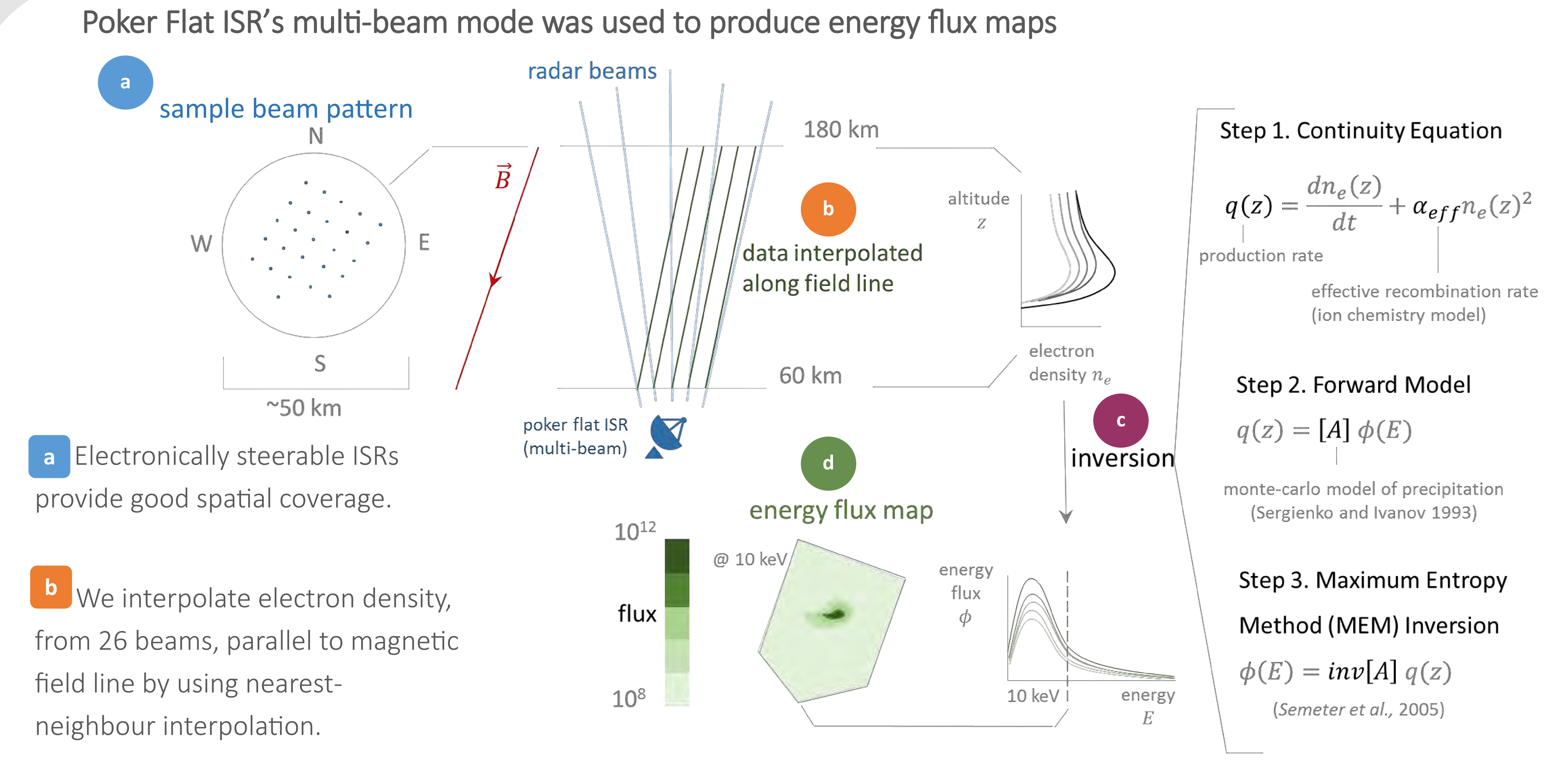
Date	Onset Time	Onset MLAT[1]	ΔMLT[2]	Onset EEP	GEEP	% of energy >10 keV	% of energy >30 keV	S/C Conjunctions
18 Oct 2007	10:55	68.57	~4.5	YES	NO	-	-	-
16 Feb 2008	08:20	71.4	~0.8	NO	NO	-	-	-
26 Mar 2008	11:46	65.47	~0.8	YES	YES	82%	27%	Thm-D,E,C
28 May 2010	11:41	65.45	~0.6	YES	YES	45%	16%	Thm-D,E,A, REIMEI,FAST
18 Oct 2010	09:24	66.24	~0.6	YES	YES	96%	76%	-
21 Jan 2011	14:31	70.60	~0	NO	unclear	-	-	-

[1]MLAT of PFISR = 65.47°N [2]ΔMLT = Onset MLT—PFISR MLT

Fig 5. We believe that GEEP is observed equatorward of the growth phase arc, in the diffuse auroral region—that corresponds to central plasma sheet. This region overlaps with the radiation belts. The GEEP is observed only for substorms where the central plasma sheet region crosses the PFISR field of view, which happens mainly for substorms with MLAT and MLT close to PFISR. The substorm MLAT and MLT are calculated using SuperMAG database (Gjerloev et al. 2012)

Methodology

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



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.

Conclusion

Key Findings

- Growth-phase Energetic Precipitation (GEEP) is an east-west aligned band of precipitating electrons up to 100 keV observed during substorm growth-phase.
- The size of GEEP seem to be about 10-20 km for 100 keV electron precipitation
- They are located equatorward of the discrete auroral arc, overlapping with the diffuse auroral region.
- About 80% of energy of GEEP comes from electrons >10 keV.

Future Work

- Estimate the loss rate of energetic particles from the magnetosphere using quantitative estimates of the energy spectra.
- Magnetically conjugate in-situ measurements from spacecrafts in low earth orbit, plasma sheet and radiation belts will help us narrow down on the source.

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