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Equatorial electron flux pulsations correlated with ground-based pulsating aurora observations

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Abstract

Pulsating aurora (PA) is a common ionospheric phenomenon and as such offers a unique opportunity to study the source of the precipitating particle populations. Whistler-mode chorus waves are naturally occurring magnetospheric plasma waves that are distinguished as a discrete superposition of quasi-monochromatic emissions and it is thought that they are the mechanism for pitch angle scattering of energetic electrons into the loss-cone. The dominant source of loss-cone scattering for energetic equatorial electrons, which can then precipitate as PA, has been explored, but not yet clearly identified. Here we use simultaneous satellite- and ground-based data to show that there is an intimate relationship between frequencies of equatorial electron flux pulsations and PA luminosity in the corresponding ionospheric magnetic footprint. Observations of a typical PA event were obtained on March 15, 2008 using the THEMIS all-sky imager (ASI) array. The field line footprint of the geostationary GOES 13 satellite, mapped down to the ionosphere at ~200 km, is located within the field-of-view of the ASIs. The Magnetospheric Electron Detector (MAGED) on GOES 13 consists of a crossed-fan array of nine solid-state detector telescopes, with each telescope reporting electron fluxes in five energy channels from 30 to 600 keV. We computed an array of the correlation coefficients between the pixel luminosity for each individual pixel of the ASI images and the flux measurements at the satellite. The results show regions of strong correlation between the luminosity fluctuations on the ground and particle pulsations in space. We also report a preliminary quantification of loss-cone coverage of each telescope and how it changed in response to magnetospheric dynamics.

Background

It is generally believed that pulsating aurora is caused by energetic electrons [1,2], precipitated by pitch angle diffusion in the vicinity of the equatorial regions of the magnetosphere [3,4,5], a result based on velocity dispersion analyses of sounding rocket observations of energetic electrons in conjunction with pulsating aurora [6,7]. These studies have consistently concluded that the electron populations must originate from geosynchronous orbit, perhaps as a result of scattering via VLF "chorus" or hiss.

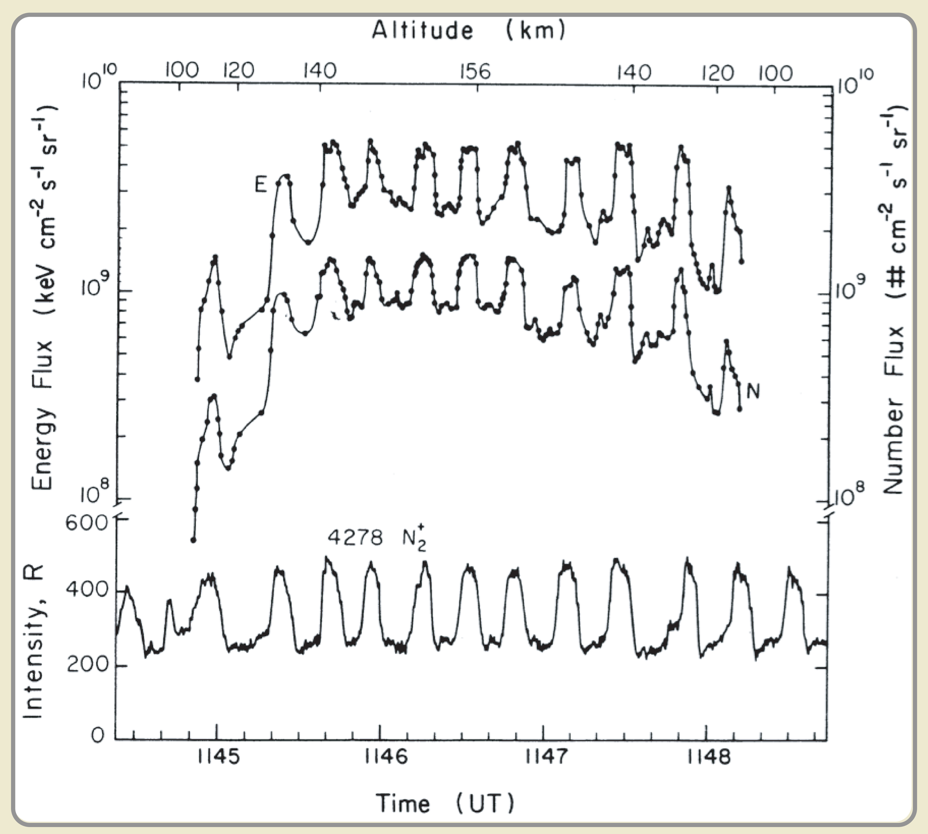


Fig. 1 - Electron fluxes observed from a sounding rocket (upper two traces) plotted with ground-based optical data (lower trace) [2]. Eleven pulsations are clearly shown in all traces.

Whistler-mode chorus waves are naturally occurring magnetospheric plasma waves that are distinguished as a discrete superposition of quasi-monochromatic emissions [8]. These wave bursts are generated near the magnetic equator [9,10, 11, 12], and it is thought that they are the mechanism for pitch angle scattering of energetic electrons into the loss-cone [13, 14, 15].

The dominant source of loss-cone scattering for energetic equatorial electrons, which can then precipitate as PA, has been explored, but not yet clearly identified. In this study, we use simultaneous satellite- and ground-based data to show that there is a one-to-one response between frequencies of electron flux pulsations in space and PA luminosity in the corresponding magnetic region of the ionosphere. This result had only been inferred through rocket observations since the 1960's and has now been confirmed.

Electron Detector

MAGnetospheric Electron Dectector (MAGED) on GOES 13 satellite

- Geosynchronous orbit near magnetic equator at ~6.6 R_E
- 9 SSD telescopes in crossed-fan arrangement (Fig. 2)
- FWHM of 20 degrees each
- Each telescope measures electron fluxes in five energy channels: 30-50 keV, 50-100 keV, 100-200 keV, 200-350 keV and 350-600 keV
- Center pitch angles derived from GOES Magnetometer data
- GOES13 can fly in upright or inverted position, with T7 and T9 typically being nearest to $\alpha = 0$ in each respective position
- Obtain time-varying pitch angle and magnetic measurements concurrently with particle fluxes

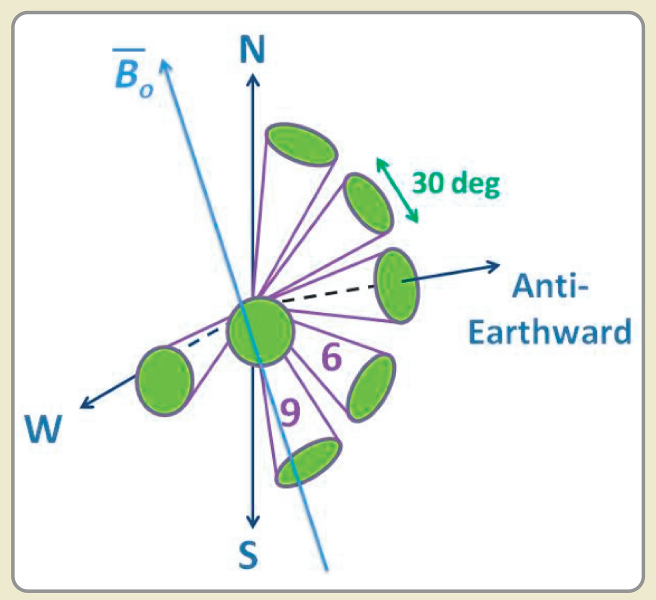
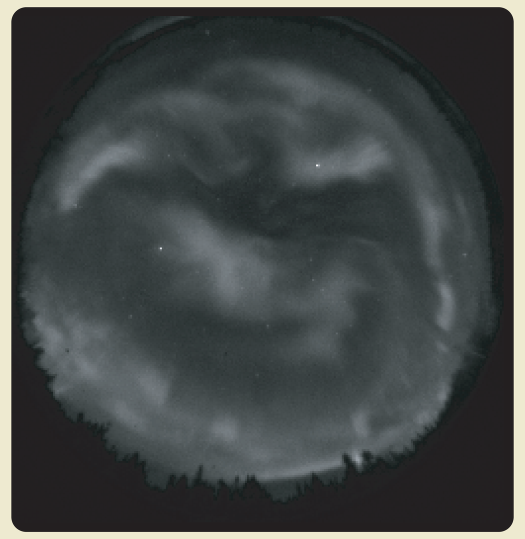


Fig. 2 - Schematic of GOES 13 MAGED telescope array

Methodology



- GOES 13 footpoint maps well to the THEMIS ASI at The Pas, Manitoba (designated TPAS)
- Several periods of significant fluctuations in equatorial particle flux were seen with MAGED on 15 March, 2008
- The most notable period, from 1100-1140 UT, corresponds with ASI pulsating aurora observations
- Positioned at 105.3 W, with local midnight occuring at 0700 UT
- GOES 13 was flying in the inverted configuration during this event

At first glance, a connection can be seen between the intense pulsations at GOES 13 and PA luminosity fluctuations (Fig. 4), including fine structure characteristics seen in both. In order to obtain an analytical measure of the similarities between the two data sets, we computed an array of correlation coefficients between the pixel luminosity for each individual pixel of the allsky and the particle flux measurements at the satellite. The ASI has a cadence of 3 seconds and thus produces 600 images (each 256x256) every 30 minutes. We sampled pixels in a grid covering the entire FOV, and correlated each sample pixel's luminosity fluctuations with GOES 13 pulsations, for varying durations of time (1 minute up to a full 30 mintues) - the result is a matrix of correlation coefficients.

Data

- Analysis focused on the 30-50 keV channel of Telescope 9 (top row, Fig. 3), as that channel had the most distinct pulsations
- Telescope 9 was the MAGED telescope most closely field-aligned during this time

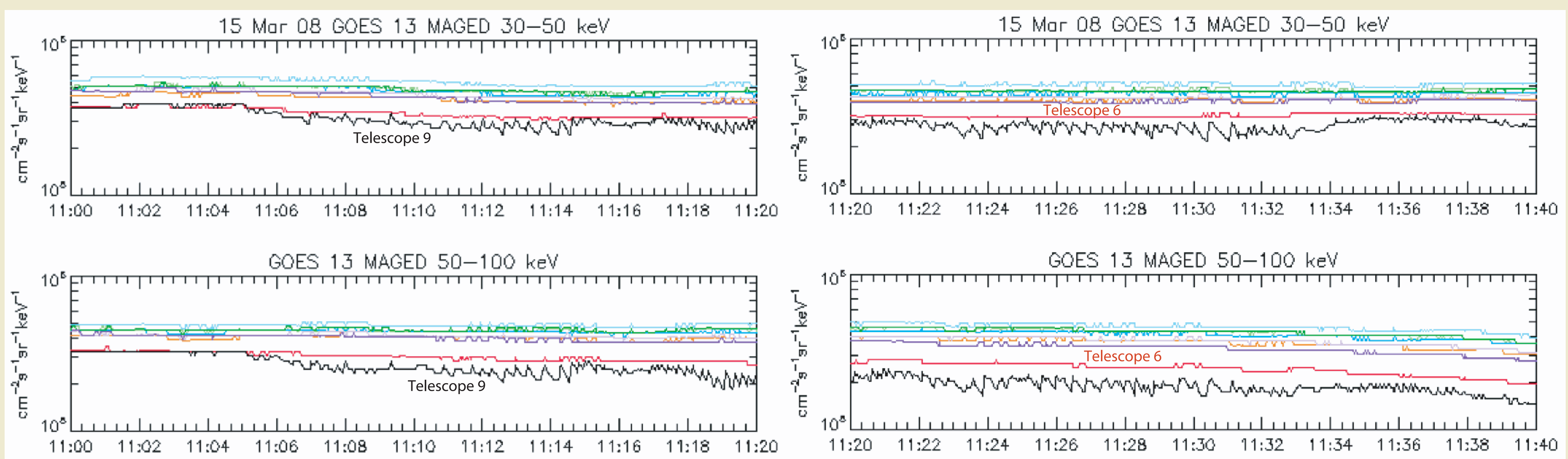


Fig. 3 - GOES 13 electron flux pulsations for 1100-1130 UT. Top row: energy channel (30-50 keV) used for correlation. Bottom row: 50-100 keV energy channel to show pulsations are present there as well. Black trace is the most closely field-aligned Telescope 9. Red trace is Telescope 6.

- Analogous features can be identified by examining a time series of both the GOES 13 flux and a chosen pixel luminosity from the ASI (Fig. 4)
- For this plot, the pixel sampled is the one that has the highest correlation with the flux data over the full 30 minute period
- One interesting detail is the clear double-peak formations that can often be seen in both plots
- A larger-scale sawtooth component is evident in both plots; this feature can be interpreted as a loading and dumping cycle for the particle populations, with the abrupt upward jump of the sawtooth showing the dumping phase of the period where the source electron pitch angles are scattered and the PA patch turns "on" down the field line as a result
- The average periods are similar with values of ~24 seconds for the PA pixel luminosity and ~26 seconds for the GOES flux measurements

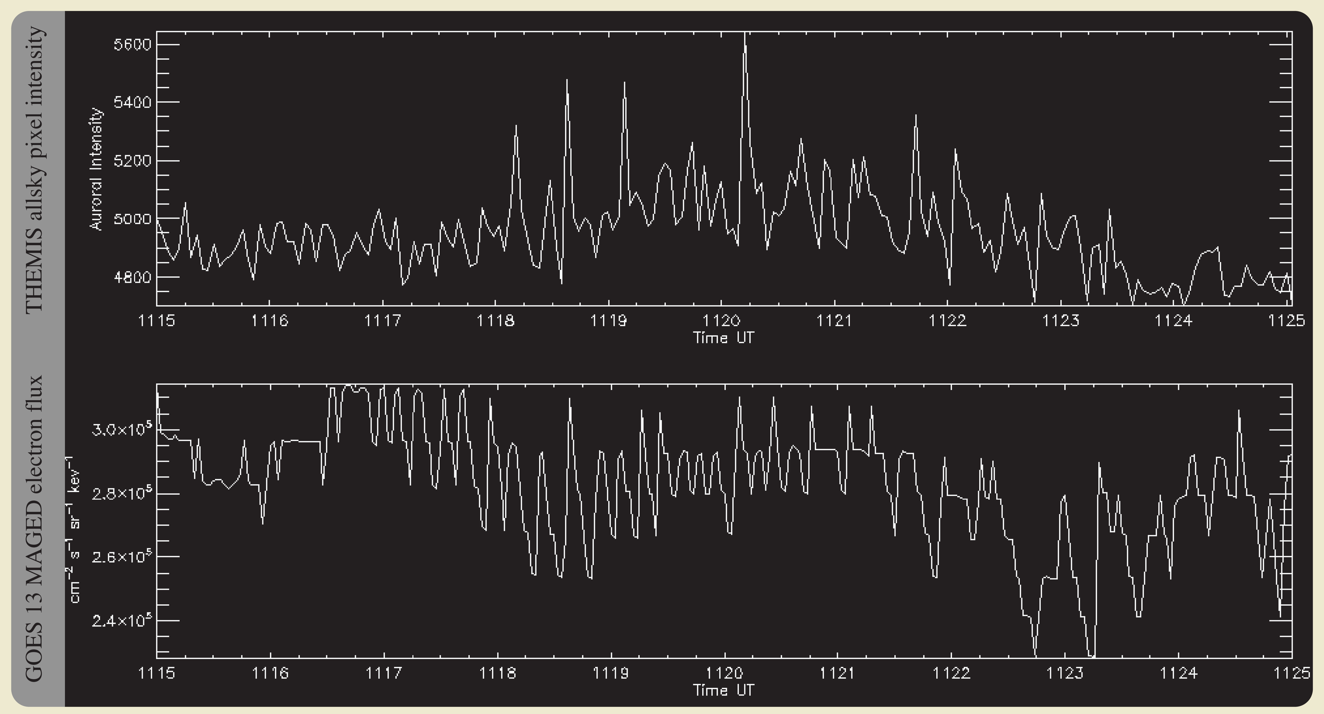


Fig. 3 - Concurrent time series of pixel intensity and electron flux

Correlation

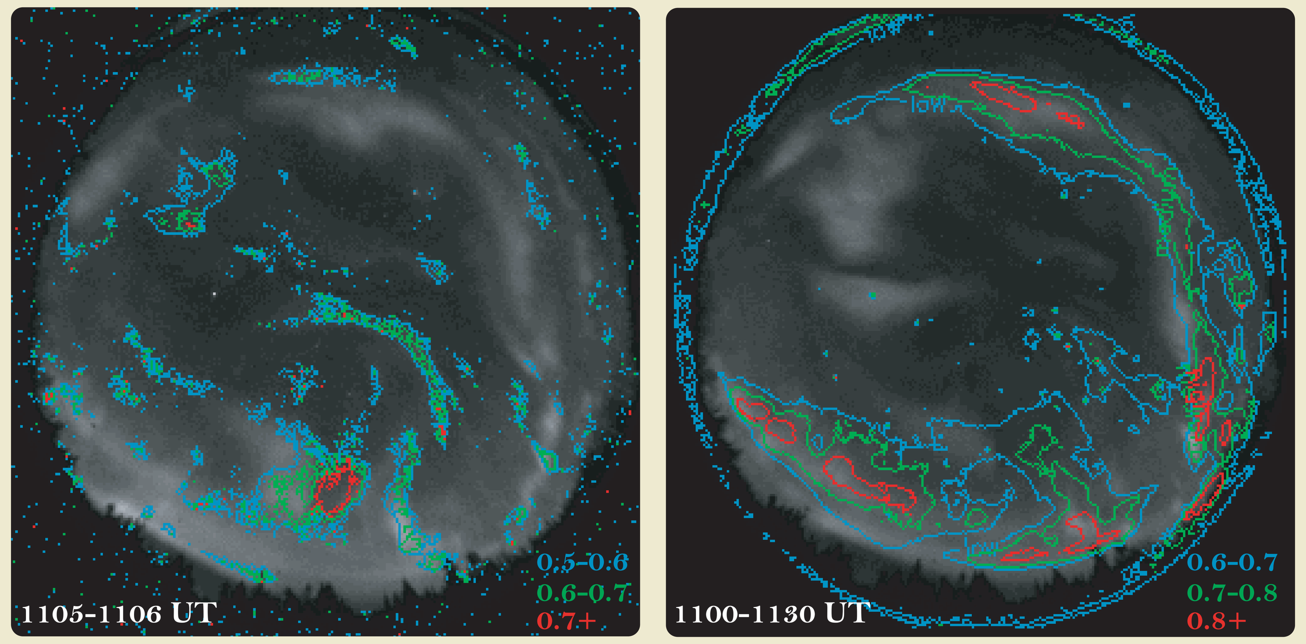


Fig. 5 - Contour plots of correlation coefficients for a 1 minute duration (left) and for the entire 30 minutes (right)

Contour plots of the correlation coefficients for each time duration are shown above in Fig. 5. Contours are plotted over a single allsky image. Different coloring scales are used for each plot, as indicated.

The 30-minute contour correlation plot shows outstanding correlations in several distinct areas. In particular, the region in the lower right hand section of the image contains the set of pixels that have been mapped most closely to the footprint of the equatorial GOES 13 location. However, during the 30 minute interval, the mapped footpoint jumped around erratically at times (see Fig. 6 below). This results in a 30 minute plot of several differing areas of high correlation, while for smaller time scales we see high correlation in a more concentrated region.

- For 1 minute plot, maximum correlation coefficient is 0.74
- For 30 minute plot, maximum correlation coefficient is 0.90

The location of GOES 13 was traced to 100 km altitude using the TS05 model with OMNI solar wind data as input. Figure 6 shows the Northern hemisphere footprint of the satellite between 0700 and 1500 UT, on 15 March 2008. These locations lie in the northwest quadrant of the field-of-view of the THEMIS all-sky imager at TPAS. There was a dramatic shift in footprint location (white trace on figure) from 1115-1130, during the time of high pulsations.

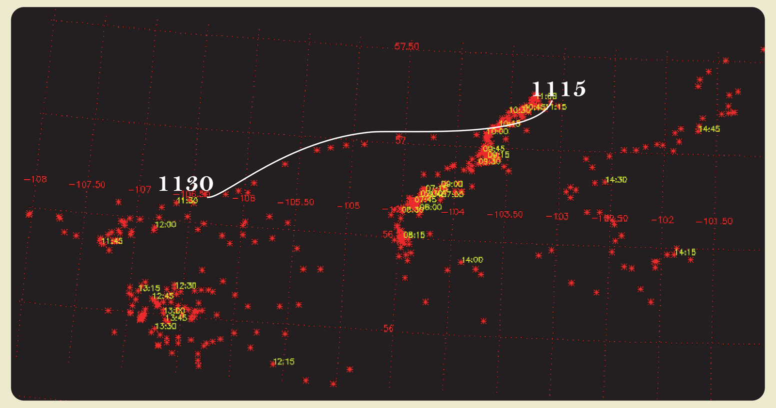


Fig. 6 - GOES 13 footprint mapped in Northern hemisphere

Conclusions

- Pulsating aurora offers a unique opportunity to study the source of the precipitating particle populations, as we have done in this study
- Geosynchronous observations of electron fluxes and pitch angles in the equatorial region can be measured with the GOES 13 MAGED telescope array
- In the event presented, we see a clear correlation between pulsating aurora modulations and electron flux pulsations at GOES 13 while it is located along a field line over a region of widespread and persistent pulsating aurora on the ground
- One result not shown here is the preliminary quantification of loss-cone coverage of each telescope and how that changed in response to magnetospheric dynamics: we ONLY observed these modulations in the field-aligned telescope at any given time

• This satellite- and ground-based study shows occurrences of equatorial electron fluctuations at geosynchronous orbit that coincide directly with ground observations of PA

Remaining Questions:
What exactly are the wave-particle interactions happening in the equatorial magnetosphere? Chorus waves?
Can we better quantify the loss cone converage of the MAGED telescopes? This would allow us to contrain the pitch angle range contributing to the fluctuations.

References:
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