AARDDVARK Loop Antenna, Halley
[credit: Jeff A. Cohen]

A Model of Energetic Electron Precipitation During Space Weather Events

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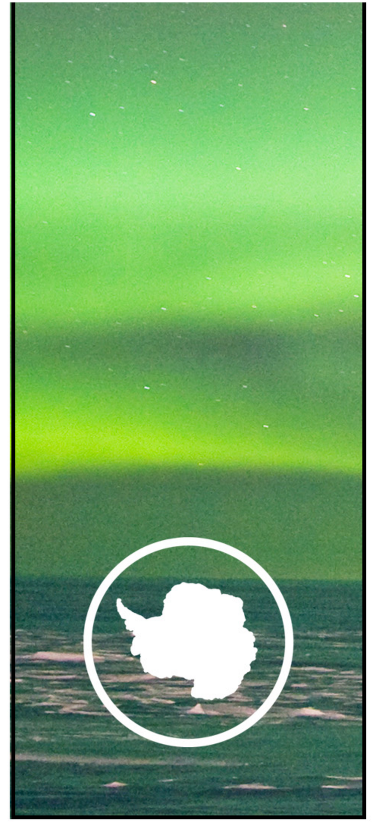


ABSTRACT

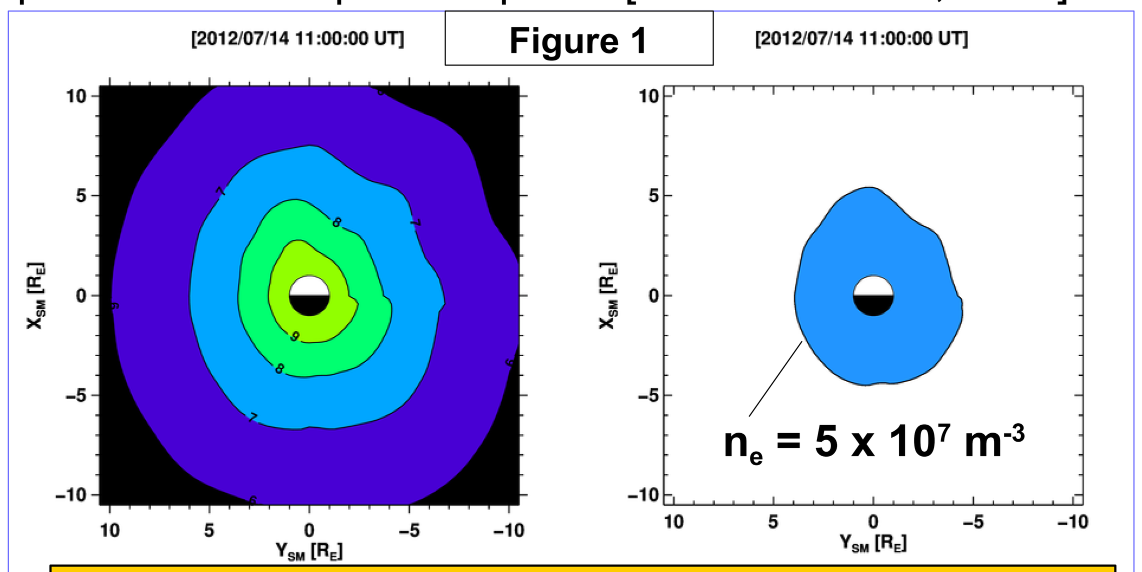
The outer edge of the plasmasphere has a strong influence on the geographic location of high energy particle precipitation into the atmosphere. In this study, we will present a description of the PLASMON [FP7-funded project] developed model of energetic electron precipitation (EEP) fluxes inside and outside of the plasmasphere during space weather events. The aim of the PLASMON EEP model is to identify energetic electron precipitation into the ionosphere generated by ULF/VLF waves in the magnetosphere. Wave generation is influenced by MLT-dependent plasmaspheric density structures such as the plasmapause. During geomagnetic disturbances the intensities of the ULF/VLF waves are enhanced, plasmaspheric structures are modified, and differing levels of precipitation flux are generated. The model will characterise the variations in electron precipitation relative to the plasmapause, building on the outputs of the PLASMON data assimilative model of the plasmasphere, and observations of EEP characteristics made by the PLASMON ground-based VLF receiver network (AARDDVARK).

Background & Motivation

Electron precipitation represents a loss from the radiation belts [*Summers et al., 2007*], as well as a source of atmospheric ionisation, which may drive changes in atmospheric chemistry [Seppälä et al, 2007] and variation in the propagation of radio signals [Clilverd et al., 2009]. Modelling of the location and strength of precipitation is therefore important for the understanding of space weather as well as atmospheric processes.

Waves driving precipitation manifest depending on the presence of the plasmasphere [Summers et al., 2007].

Figure 1



***Left**: Plasmasphere model on magnetic equator 2012-07-14 11:00 UT. Contours are $\log_{10}(n_e[m^{-3}])$.*
***Right**: Plasmapause contour at n_e = 5 x 10^7 m^{-3}.*

Plasmapause from Data Assimilative Model

To determine the location of waves, the location of the plasmapause is required. The aims of PLASMON [Lichtenberger et al., 2013] are to provide real-time plasmaspheric density data , a data-assimilative model of the plasmasphere [Jørgensen et al., 2009] and a model of REP losses.

A plasmapause can be evaluated from the data assimilative model as seen in the **Figure 1 (above)**. Here a threshold value is used, although more sophisticated plasmapause identification could be made (e.g., knee detection) as the plasmasphere model matures.

Wave-Driven Precipitation Model

Once the location of the plasmapause is known, estimates of precipitation flux can be added. The regions for each type of wave-driven precipitation flux are [Summers et al., 2007; Whittaker et al., 2014]:

Chorus *Lpp < L < 9 ; 23h < MLT < 11h (+tapering)*
Hiss *3.1 < L < 4.2 ; 11h < MLT < 16h*
EMIC *Lpp < L < Lpp+1 ; 16h < MLT < 23h*

The fluxes were estimated using algorithms based on POES data for hiss & chorus [Hendry et al., 2012; Whittaker et al., 2014] for EMIC. The algorithms are:

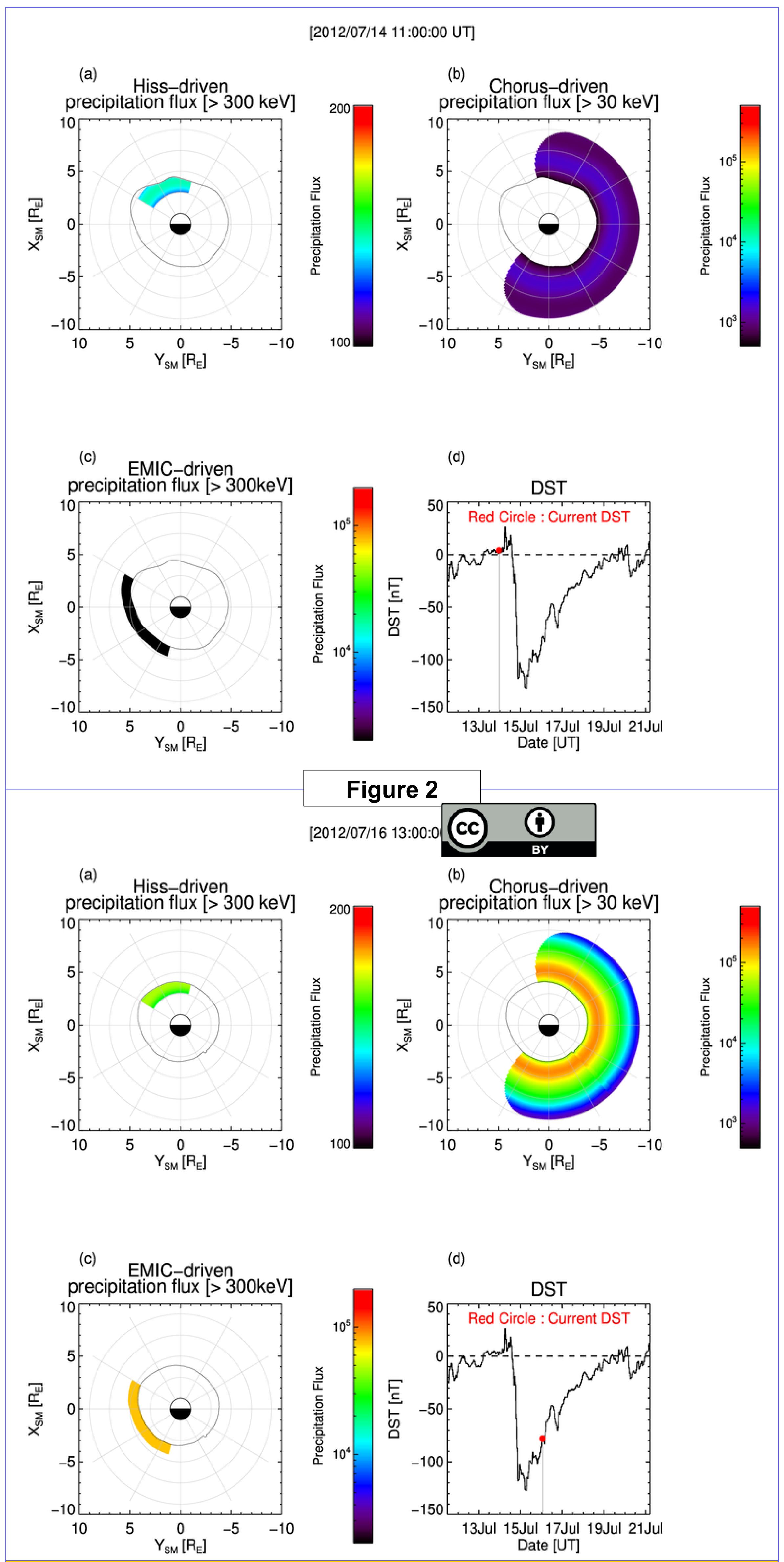
$$flux_{chorus(>30keV)} = C_1 |Dst|^{2.8} + C_2$$

$$flux_{hiss(>300keV)} = C_3 |Dst_{t-48h}|^{0.065}$$

$$flux_{EMIC(>300keV)} = \begin{cases} |Dst| \times 10^3 : Kp \geq 4 \\ 0 : Kp < 4 \end{cases}$$

...in units of (cm^2 s sr)$^{-1}$, with: C_1, C_2 & C_3 as functions of L-shell

These fluxes are shown for two times during the storm of July 2012 in **Figure 2 (centre column)**.



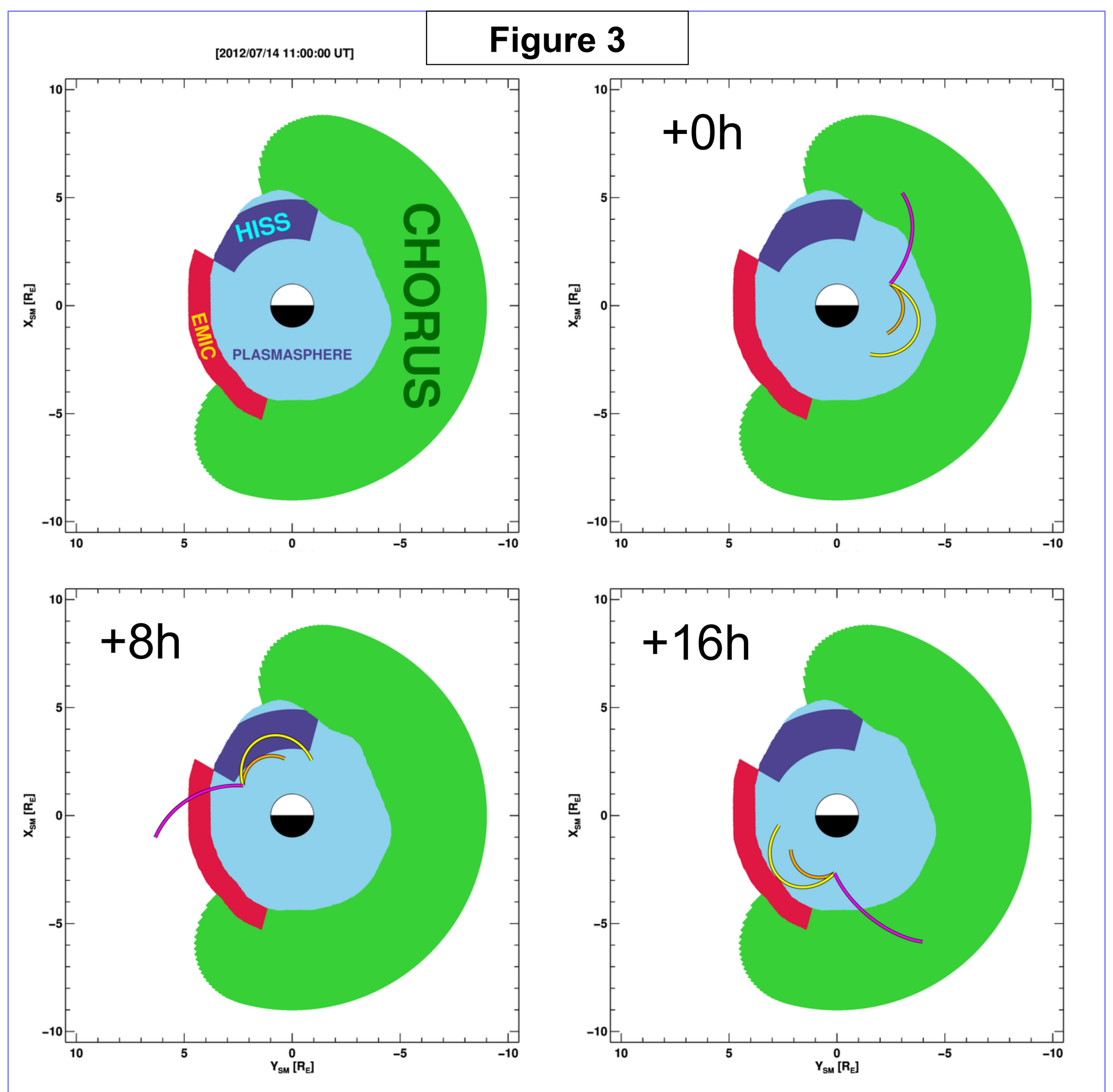
*Two snapshots (**top**: 2012/07/14 1100 UT **bottom**: 2012/07/16 1300 UT) of the model during the geomagnetic storm of July 2012. Modelled wave-driven electron precipitation fluxes [(cm^2 s sr)$^{-1}$] are shown. All flux colour-scales are logarithmic. Also shown, the Dst in context (**panels (d)**) of the time series during the July 2012 storm.*

Radio Propagation Path Mapping

The direct line propagation path between VLF military communication transmitters and AARDDVARK VLF receivers can be mapped to the magnetic equator. This enables judgement on whether precipitation along the path may affect amplitude or phase of signals received. Precipitation driven by chorus, hiss and EMIC waves may be detectable by using the VLF method.

Example propagation paths are shown in **Figure 3 (right-hand column)**. Each path has a different range in L-shell and MLT, although the MLT of the paths change with the Earth's rotation.

Figure 3



***Top left**: Regions for waves potentially responsible for precipitation. **Other panels**: AARDDVARK radio paths mapped to the magnetic equator 1100, 1900 & 0300UT (+0h,+8h,+16h). Paths are St. John's, Canada, from Keflavík, Iceland (**magenta**), N. Dakota, USA (**orange**) & Seattle, USA (**yellow**)*

Summary

The plasmapause is of vital importance in the distribution of waves and wave-driven precipitation. To be able to investigate the effects of wave-driven precipitation, knowledge of the location of the plasmapause is essential. To serve this purpose the PLASMON data assimilative plasmasphere model is a useful tool.

With information on the plasmapause, a model of the wave-driven precipitation can be constructed using relationships based on empirical data.

AADDVARK VLF radio propagation measurements are then suitable to cross-reference the model of wave-driven precipitation based on the PLASMON plasmasphere.

Acknowledgements

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References

Hendry et al., *Rapid Radiation Belt Losses Occurring During High-Speed Solar Wind Stream–Driven Storms: Importance of Energetic Electron Precipitation*, Geophysical Monograph Series 199 **(2012)**

Summers et al., *Timescales for radiation belt electron acceleration and loss due to resonant wave-particle interactions*, JGR **(2007)**

Seppälä et al., *NOx enhancements in the middle atmosphere during 2003 -- 2004 polar winter: Relative significance of solar proton events and the aurora as a source*, JGR **(2007)**

Clilverd et al., *Remote sensing space weather events: Antarctic-Arctic Radiation-belt (Dynamic) Deposition-VLF Atmospheric Research Konsortium network*, Space Weather **(2009)**

Jørgensen et al., *Specification of the Earth's plasmasphere with data assimilation*, Advances in Space Research **(2009)**

Lichtenberger et al., *The plasmasphere during a space weather event: first results from the PLASMON project*, J. Space Weather Space Clim. **(2013)**

Whittaker et al., *Properties of electron flux spectra around the plasmapause in the chorus and hiss regions using POES*, EGU Poster 2014-4568 **(2014)**