On the relation between soft electron precipitation in the cusp region and solar wind coupling functions

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Abstract

Using the LFM simulations, in this study, we investigate the correlations between the fluxes of precipitating soft electrons in the cusp region and solar wind coupling functions. We find that:

1.Cusp plasma density at high altitudes correlates well with solar wind plasma density. The plasma density ratio ncusp/nsw is 0.78, which agrees well with the observation results from Walsh et al. [2016].

2.The number flux and energy flux of cusp soft electron precipitation correlates best with SW dynamic pressure.

3.The direct-entry cusp soft electron exhibits significant hemispheric asymmetry at solstice.

1. Introduction

The polar cusp provides a direct access which allows the solar wind plasma of the magnetosheath to enter the magnetosphere and the ionosphere at low altitudes.

Cusp electrons have a relatively soft energy (~several hundred eV) compared with diffuse electrons (~keV)

The soft electron plays an important role in ionosphere/thermosphere (IT) system, i.e., the ionospheric upflow and cusp thermispheric density enhancement. However, the cusp soft electron precipitations has been rarely considered in the IT models.

How does the solar wind condition controls the direct entry of magnetosheath electrons in the cusp region? Due to the lack of measurements in the cusp region, it is hard to study these relations from the observations.

2. Model and Simulation Condition

The Model used in this study is Lyon-Fedder-Mobarry (LFM) global magnetosphere model, based on two event simulations near March equinox and December solstice.

Two event simulations:

The Equinox Case: 20 Mar. 2008 ~ 16 Apr. 2008

The Solstice Case: 15 Dec. 2014 ~ 24 Dec. 2014

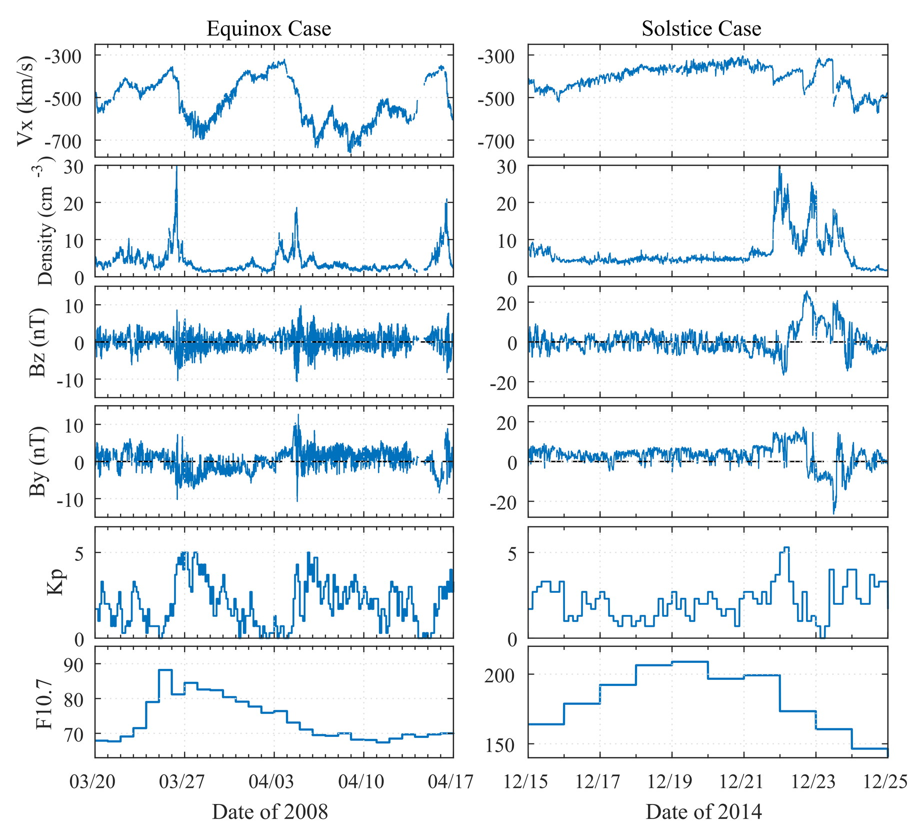


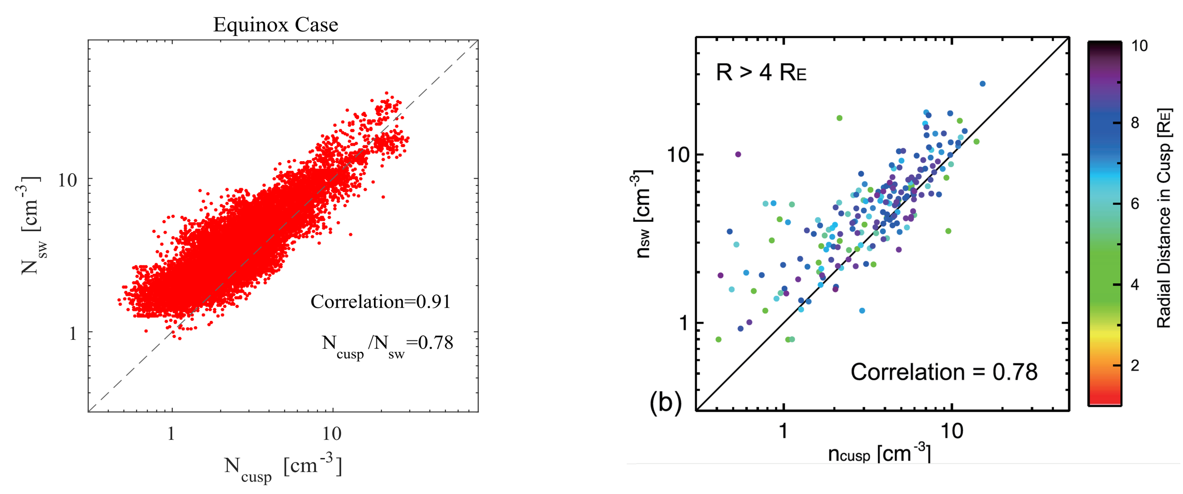
Figure 1. Geomagnetic condition of two event simulations.

1.SW velocity and density cover wide ranges

2.Geomagnetically quiet condictions

3.1 Equinox Case: Cusp Density vs SW Density

Figure 2. Cusp plasma number density at 5 RE altitude versus solar wind density.



LFM results:
Mean Ncusp/Nsw=0.78

Walsh et al. [2016]:
Mean Ncusp/Nsw=0.8

High coorelation between solar wind density and cusp plasma density at 5 RE.

The average plasma density ratio Ncusp/Nsw (0.78) agrees well with the ratio of 0.8 in the observations of Walsh et al. [2016].

3.2 Equinox Case
Cusp Electron Precipitation vs SW-Couping Function

hemispheric electron rate | hemispheric electron power

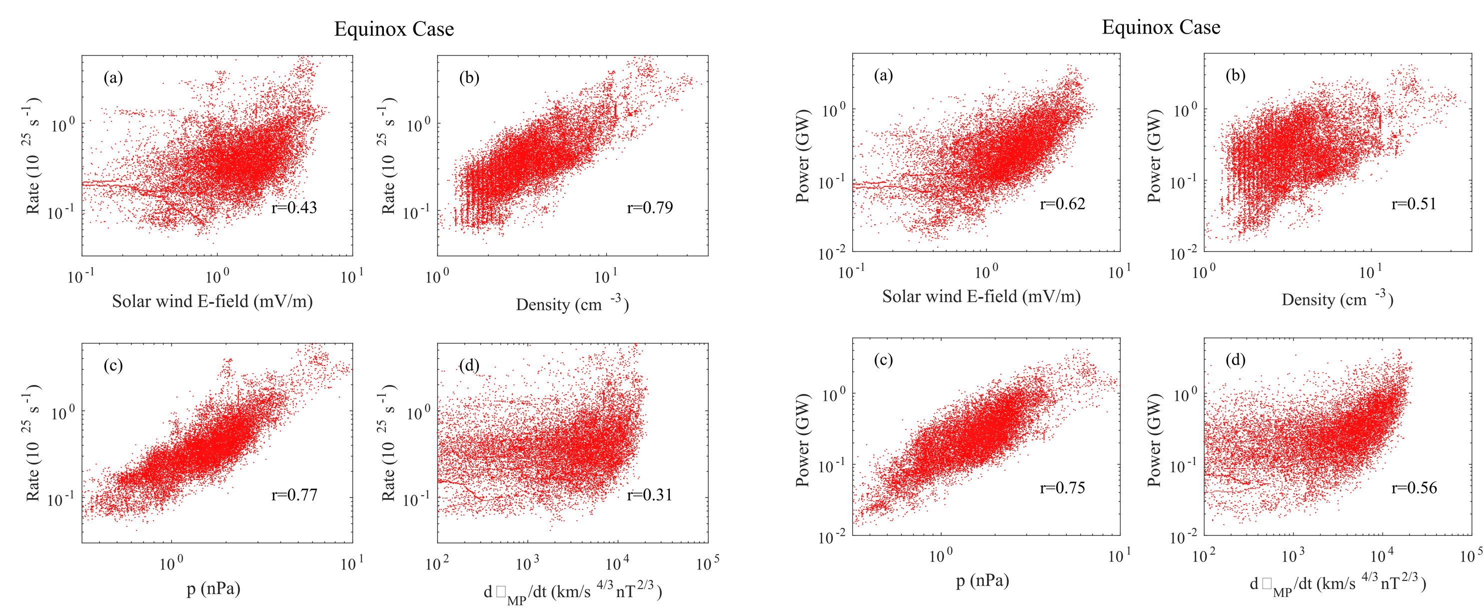


Figure 3. Scatterplots of hemispheric precipitation rate of soft electrons versus solar wind electric field, density, dynamic pressure, and dayside merging rate.

Both the hemispheric soft electron precipitation rate and power have a good correlation with solar wind dynamic pressure.

We also performed the linear correlations between 20 SW-coupling functions and cusp soft electron precipitations, as listed in Table 1.

Equinox Case: Solar wind dynamic pressure correlates best! The empirical linear relations are obtained:

$$Power = 0.266\,p - 0.110 \qquad Rate = 0.425\,p - 0.214$$

Name	Function Form	Precipitation Rate	Hemispheric Power
B_z	B_z	-0.27	-0.38
Velocity	v	-0.15	0.22
Density	n	0.79	0.51
p	$nv^2/2$	0.77	0.75
B_s	$\begin{cases} B_z & (B_z < 0) \\ 0 & (B_z > 0) \end{cases}$	-0.46	-0.56
Half-wave rectifier	vB_s	-0.39	-0.58
ε	$vB^2 \sin^4(\theta_c/2)$	0.53	0.68
ε_1	$vB_T^2 \sin^4(\theta_c/2)$	0.53	0.68
ε_2	$vB \sin^4(\theta_c/2)$	0.41	0.61
Solar wind E-field	vB_T	0.43	0.62
E_{KL}	$vB_T \sin^2(\theta_c/2)$	0.42	0.64
$E_{KL}^{1/2}$	$[vB_T \sin^2(\theta_c/2)]^{1/2}$	0.36	0.56
E_{KLV}	$v^{4/3} B_T \sin^2(\theta_c/2)\, p^{1/6}$	0.45	0.68
E_{WAV}	$vB_T \sin^4(\theta_c/2)$	0.41	0.61
E_{WAV}^2	$[vB_T \sin^4(\theta_c/2)]^2$	0.43	0.62
$E_{WAV}^{1/2}$	$[vB_T \sin^4(\theta_c/2)]^{1/2}$	0.35	0.54
E_{WV}	$v^{4/3} B_T \sin^4(\theta_c/2)\, p^{1/6}$	0.43	0.65
E_{SR}	$vB_T \sin^4(\theta_c/2)\, p^{1/6}$	0.55	0.73
E_{TL}	$n^{1/2} v^2 B_T \sin^6(\theta_c/2)$	0.53	0.69
$d\Phi_{MP}/dt$	$v^{4/3} B_T^{2/3} \sin^{8/3}(\theta_c/2)$	0.31	0.56

Table 1. The linear correlation between SW coupling functions and cusp soft electron precipitation rate and hemispheric power derived from the Equinox Case simulation.

4.1 Solstice Case: Cusp Density vs SW Density

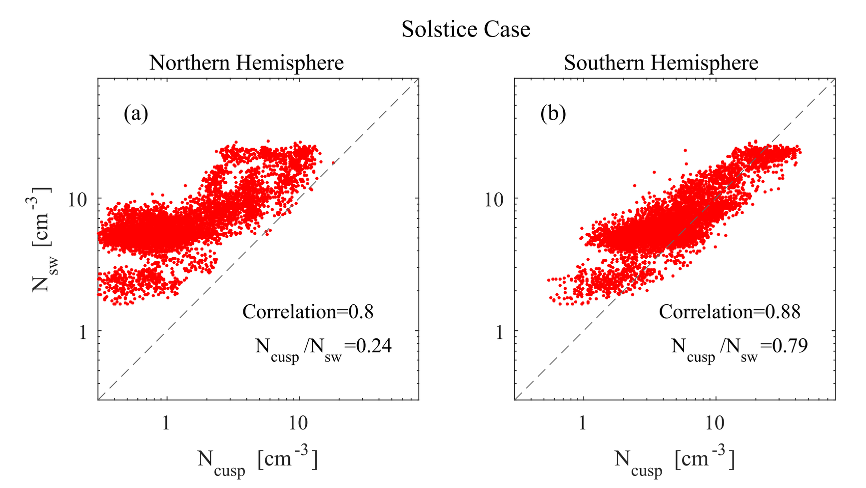


Figure 4. The cusp plasma number density for the Northern Hemisphere (left) and Southern Hemisphere (right) as a function of solar wind number density derived from the "Solstice Case".

High coorelation between solar wind density and cusp density.

Hemispheric asymmetry: Ncusp/Nsw North (0.24) < South (0.79)

The Southern (summer) Hemisphere tilts more toward the sun, leading to more entry of magnetosheath electrons from solar wind.

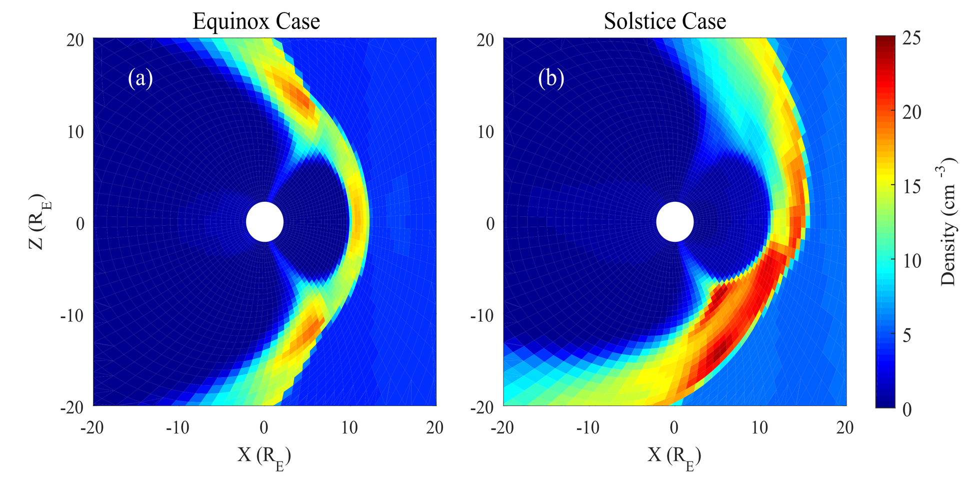


Figure 5. The distribution of plasma density in the X-Z plane at 00:00 UT on 21 Mar 2008 and 21 Dec 2014, respectively.

4.2 Solstice Case:
Cusp Electron Precipitation vs SW-Couping Function

We also performed the linear correlations between 20 SW-coupling functions and cusp soft electron precipitations at solstice. Solar wind dynamic pressure is still the best one, with correlation coefficients larger than 0.8!

The empirical linear relations are obtained:

$$Power_{sum} = 0.289\,p - 0.070$$
$$Rate_{sum} = 0.667\,p - 0.278$$
$$Power_{win} = 0.162\,p + 0.050$$
$$Rate_{win} = 0.339\,p - 0.115$$

Unit:
p: nPa
Power: GW
Rate: 10^{25} s^{-1}

5. Conclusion

(1). The LFM global simulation reproduces the observation of direct-entry of cusp soft electrons well, both in the high correlation between solar wind density and cusp density and the mean density ratio Ncusp/Nsw.

(2). The SW dynamic pressure, rather than the widely used coupling function electric field, has the best correlation with soft electron precipitations, with the correlation coefficients greater than 0.75.

(3). Significant hemispheric asymmetry can be seen for the cusp soft electron precipitation at solstice.

(4). Empirical linear relations between cusp soft electrons and SW dynami pressure are obtained to provide a possible calculation of cusp electron precipitations for ionosphere models.

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