Coordinated observations of the effect of consecutive HSS pulses on relativistic electron enhancement

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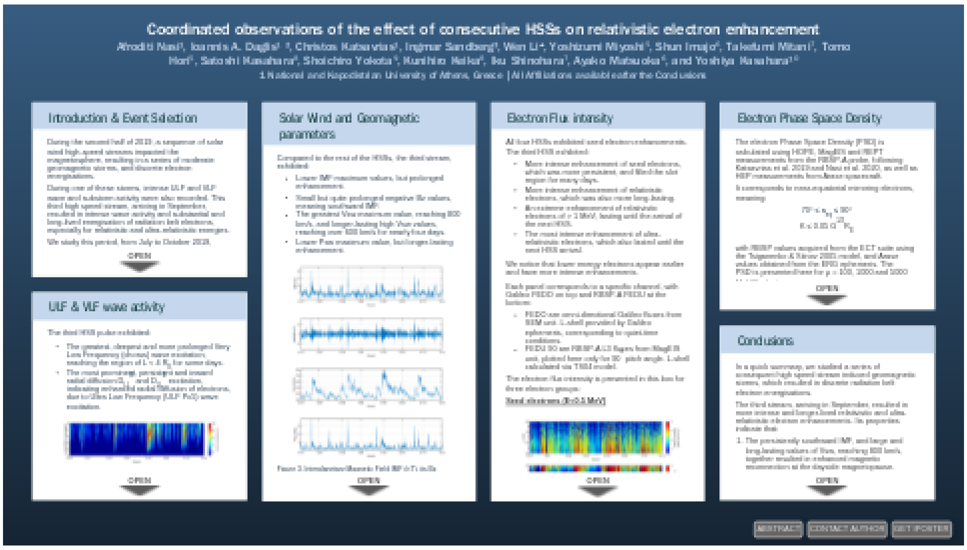
Abstract

During the second half of 2019, a series of recurring, moderate geomagnetic storms (Dst [?] - 70 nT) emerged after a sequence of high-speed solar wind streams (Vsw [?] 600 km/s) impacted the magnetosphere. During one of these storms, intense substorm activity was also recorded (SML [?] - 2000 nT on August 31 and September 1), as well as a longer-lasting solar wind pressure pulse. We investigate this series of events, using particle measurements from three missions that recorded significant enhancements of relativistic electron fluxes: the Van Allen Probes, Arase and Galileo 207 & 215 satellites. We use both the flux intensity and the phase space density (PSD) of electrons, along with interplanetary parameters and information on ultra-low frequency (ULF) and chorus wave activity for a detailed analysis of this event. Our study demonstrates the importance of substorm injections, even during moderate or weak geomagnetic storms. The presence of seed electrons at L* = 4-5, in addition to intense ULF and chorus wave activity, seems to result in very efficient electron acceleration to relativistic and ultra-relativistic energies. This work has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870437 for the SafeSpace project.

Coordinated observations of the effect of consecutive HSSs on relativistic electron enhancement



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PRESENTED AT:

INTRODUCTION, EVENT SELECTION & CONCLUSIONS

During the second half of 2019, a sequence of solar wind high-speed streams impacted the magnetosphere, resulting in a series of moderate geomagnetic storms, and discrete electron energisations.

During one of these storms, intense ULF and VLF wave and substorm activity were also recorded. This third high speed stream, arriving in September, resulted in intense wave activity and substantial and long-lived energisation of radiation belt electrons, especially for relativistic and ultra-relativistic energies.

We study this period, from July to October 2019, using electron data from three distinct missions (RBSP, Arase & Galileo) to study the electron behaviour depending on different geomagnetic and magnetospheric conditions.

Conclusions

In a quick summary, we studied a series of consequent high speed stream induced geomagnetic storms, which resulted in discrete radiation belt electron energisations.

The third stream, arriving in September, resulted in more intense and longer-lived relativistic and ultra-relativistic electron enhancements. Its properties indicate that:

1. The persistently southward IMF, and large and long-lasting values of Vsw, reaching 800 km/s, together resulted in enhanced magnetic reconnection at the dayside magnetopause.
2. The enhanced reconnection rate led to a moderate, long-lasting storm, and an extremely intense substorm, shown by SML index reaching -2000 nT.
3. The substorm activity led to source electron injections to the inner magnetosphere, which also excited VLF chorus waves.
4. The long-lived elevated Vsw and Psw led to a pronounced excitement of ULF waves in the magnetosphere, which is evident in the calculated enhanced diffusion coefficients.
5. This activity also resulted in a significant erosion of the plasmasphere, reaching the regions of $L < 4$ for many days, letting the chorus waves penetrate to these regions.
6. The synergy of chorus waves in the inner magnetosphere and of ULF waves, led to the intense energisation of electrons, via local acceleration and radial diffusion, respectively.
7. All electron populations exhibited a significant energisation, with the most intense being the enhancement of relativistic and specifically ultra-relativistic electrons, which was a characteristic property of only the third high speed stream pulse, arriving in September.

This study highlights the importance of substorm injections, even during moderate or weak storms. The seed electrons along with the ULF and VLF wave activity seem to result in efficient acceleration even to ultra-relativistic energies. This is an ongoing work, and we are currently studying the relative role of the two wave types in producing this energisation.

ULF & VLF WAVE ACTIVITY

The third HSS pulse exhibited:

- The greatest, deepest and more prolonged Very Low Frequency (chorus) wave excitation, reaching the region of $L < 4\ R_E$ for some days.
- The most prominent, persistent and inward radial diffusion D_{LL}^B and D_{LL}^E excitation, indicating enhanced radial diffusion of electrons, due to Ultra Low Frequency (ULF Pc5) wave excitation.

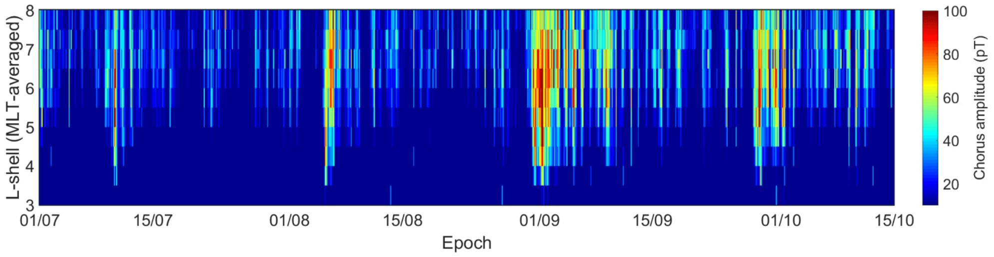

Figure 1. VLF Chorus wave amplitude (pT) inferred from POES & MetOp electron (30–100 keV) precipitation, following Li et al. 2013. The use of L instead of L* for the chorus waves is done with caution. The broad binning that we use (dL=0.5 and dT=1h), as well as the qualitative nature of this study, leads as to believe that this will not significantly affect the nature of our results.

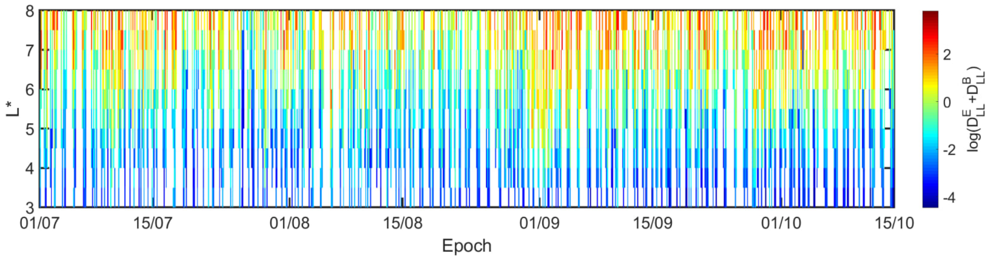

Figure 2. The sum of D_{LL}^B and D_{LL}^E. D_{LL} are radial diffusion coefficients corresponding here to Pc5 ULF waves for μ=1000 MeV/G electrons, calculated using data from THEMIS satellites. D_{LL} data acquired from the SafeSpace (https://www.safespace-h2020.eu/) database.

SOLAR WIND AND GEOMAGNETIC PARAMETERS

Compared to the rest of the HSSs, the third stream, exhibited:

- Lower IMF maximum values, but prolonged enhancement.
- Small but quite prolonged negative Bz values, meaning southward IMF.
- The greatest Vsw maximum value, reaching 800 km/s, and longer-lasting high Vsw values, reaching over 600 km/s for nearly four days.
- Lower Psw maximum value, but longer-lasting enhancement.

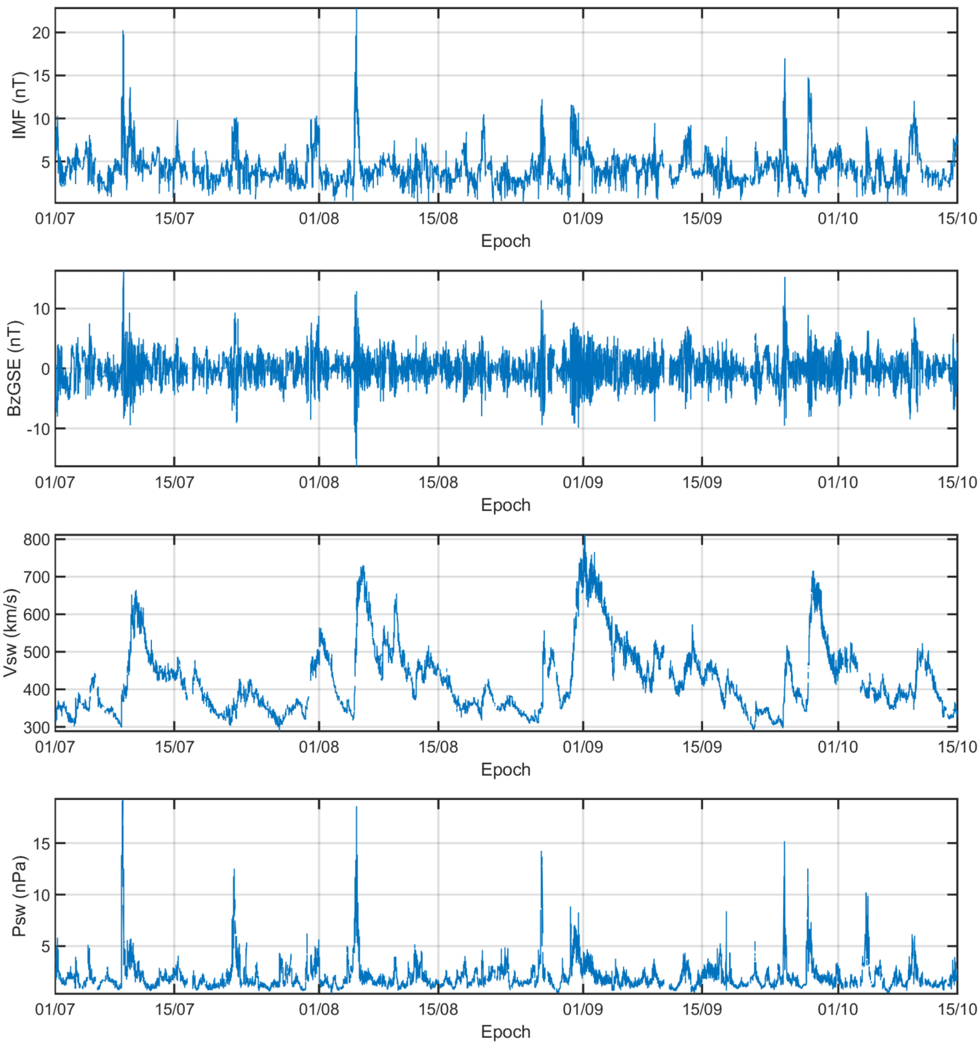

Figure 3. Interplanetary Magnetic Field IMF (nT), its Bz component (nT), Solar Wind Velocity V_{SW} (km/s) and the Solar Wind dynamic Pressure P_{SW} (nPa). Data from the NASA OMNIweb database.

Additionally, the third HSS exhibited:

- Comparable SYM-H values and duration, indicating relatively moderate geomagnetic storm activity.
- Extremely low values of SML index, reaching -2000 nT, indicating intense and prolonged substorm activity.
- Comparable but more prolonged dayside Magnetopause compression.
- Comparable but significantly prolonged Plasmapause compression, reaching the region of L < 4 R_E for nearly 10 days.

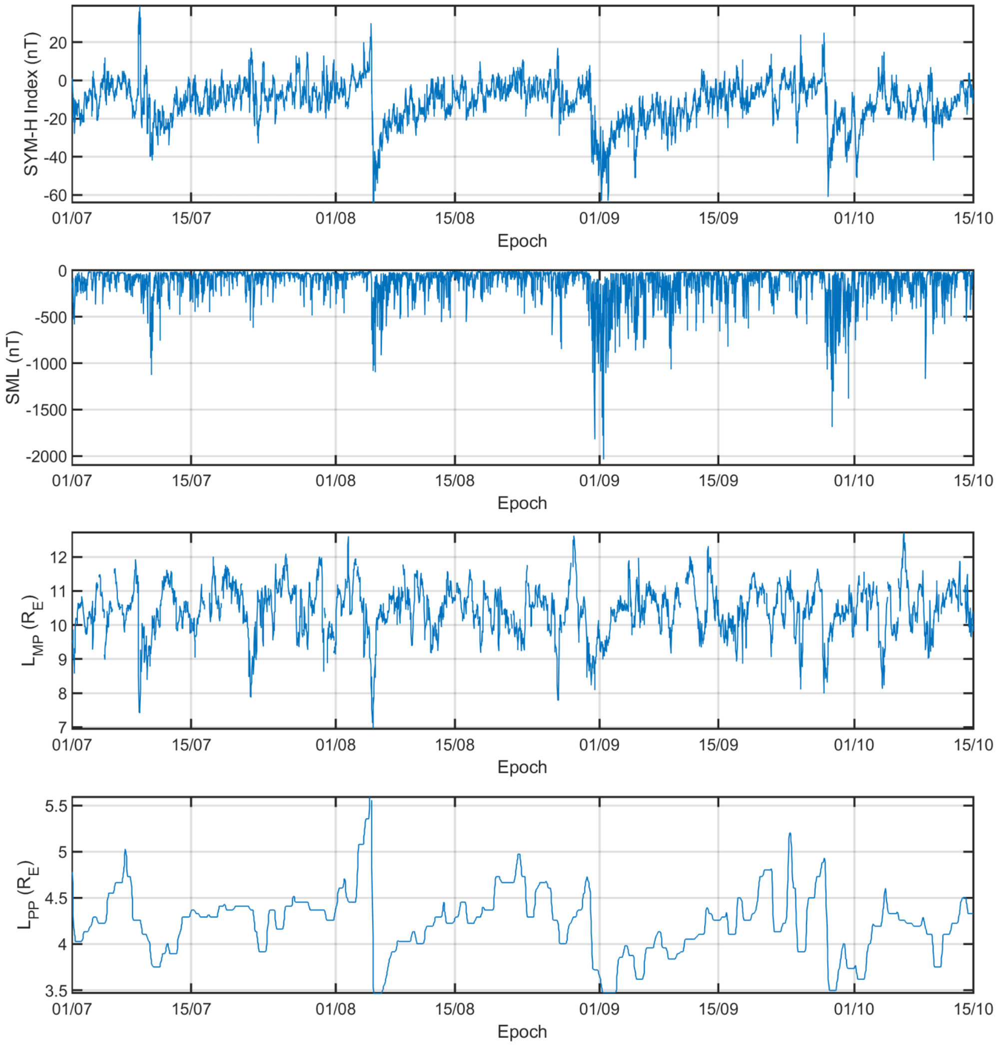

Figure 4. Geomagnetic indices SYM-H (nT) acquired from the NASA OMNIweb database, and SML index (nT) from the SUPERMAG database (similar to AL index). Location of the Magnetopause L_{MP} (R_E) calculated using Shue et al. 1998. MLT-averaged location of the Plasmapause L_{PP} (R_E) calculated using O'Brien and Moldwin 2003.

ELECTRON FLUX INTENSITY

All four HSSs exhibited seed electron enhancements. The third HSS exhibited:

- More intense enhancement of seed electrons, which was more persistent, and filled the slot region for many days.
- More intense enhancement of relativistic electrons, which was also more long-lasting.
- An extreme enhancement of relativistic electrons of > 1 MeV, lasting until the arrival of the next HSS.
- The most intense enhancement of ultra-relativistic electrons, which also lasted until the next HSS arrival.

We notice that lower energy electrons appear earlier and have more intense enhancements.

Each panel corresponds to a specific channel, with Galileo on top and RBSP-A at the bottom:

- FEDO are omni-directional Galileo fluxes from SEM unit. L-shell provided by Galileo ephemeris, corresponding to quiet-time conditions.
- FESA are spin-averaged RBSP-A fluxes from MagEIS and REPT units. L-shell calculated via TS04 model.

The electron flux intensity is presented in this box for three electron groups:

Seed electrons (E<0.5 MeV)

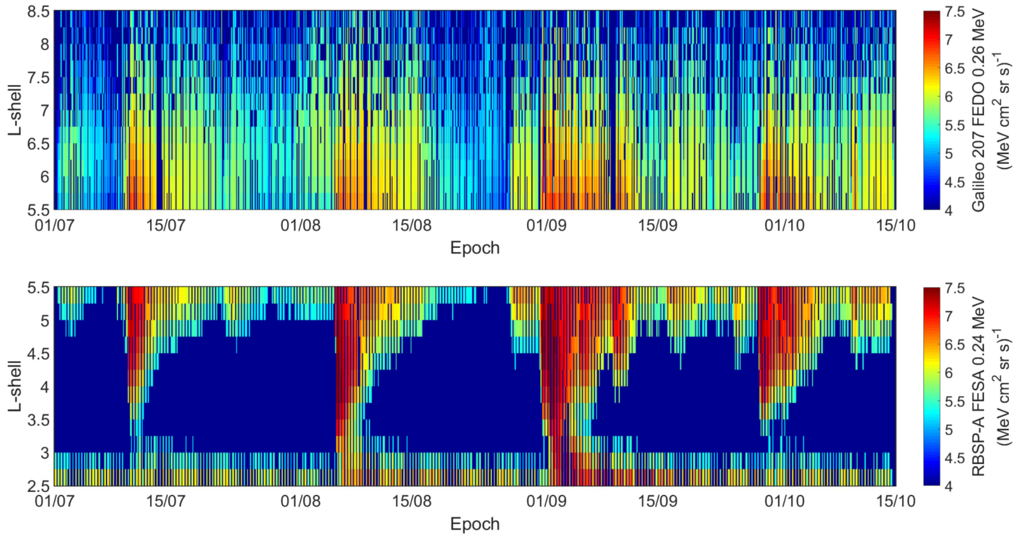

Figure 5. Electron flux for 0.26 MeV from Galileo, and for 0.24 MeV from RBSP-A spacecraft.

Relativistic electrons (E=1-2 MeV)

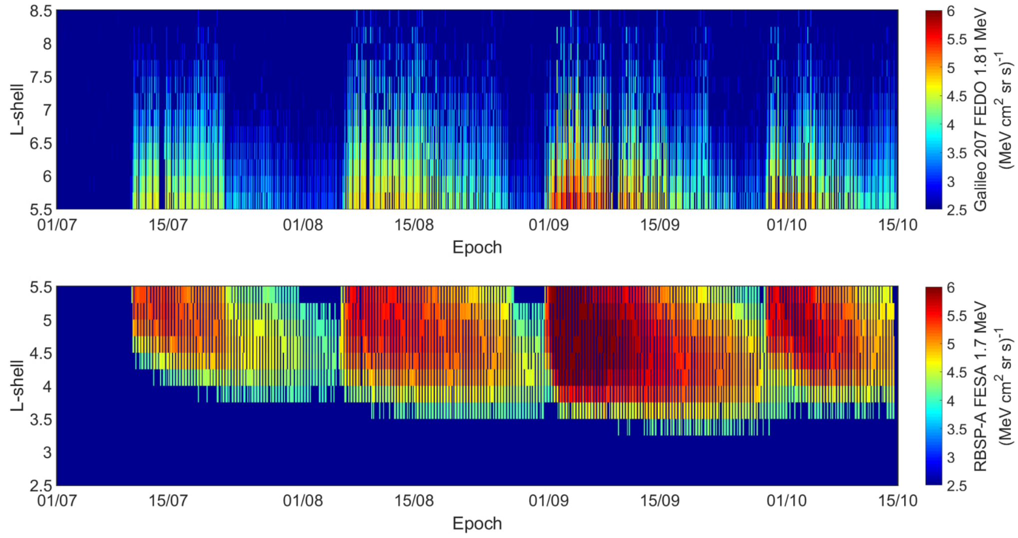

Figure 6. Electron flux for 1.81 MeV from Galileo, and for 1.7 MeV from RBSP-A spacecraft.

Ultra-relativistic electrons (E>4 MeV)

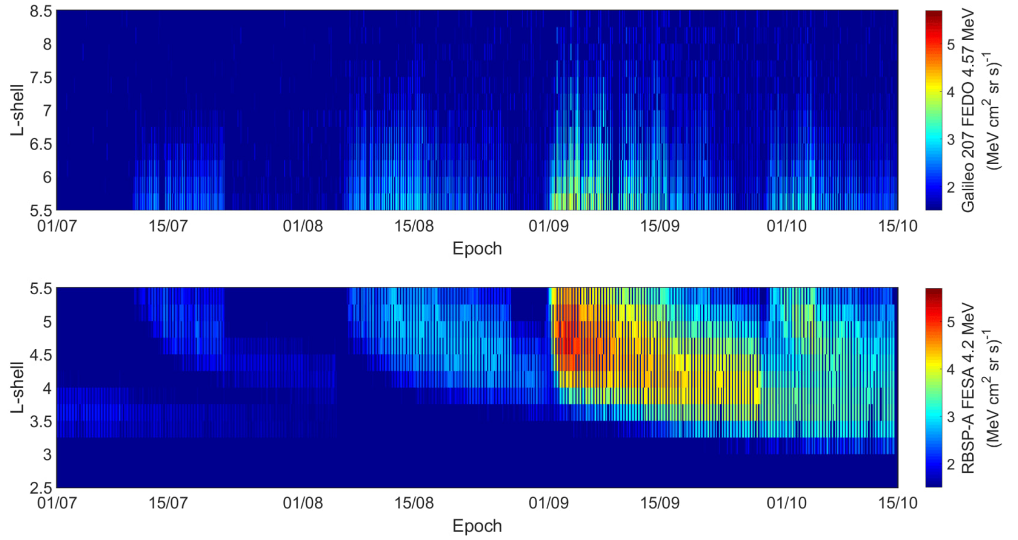

Figure 7. Electron flux for 4.57 MeV from Galileo, and for 4.2 MeV from RBSP-A spacecraft.

PRESENTATION RECORDING

[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1639505496/agu-fm2021/DB-59-23-C5-9D-88-DA-30-12-DD-CB-93-1D-FB-1D-E2/Video/eLightning_video_ioqqme.mp4

ELECTRON PHASE SPACE DENSITY

The electron Phase Space Density (PSD) is calculated using HOPE, MagEIS and REPT measurements from the RBSP-A probe, following Katsavrias et al. 2019 and Nasi et al. 2020, as well as HEP measurements from Arase spacecraft.

It corresponds to near-equatorial mirroring electrons, meaning:

$$70° \leq a_{eq} \leq 90°$$

$$K \leq 0.05\ G^{1/2}R_E$$

with RBSP values acquired from the ECT suite using the Tsiganenko & Sitnov 2005 model, and Arase values obtained from the ERG ephemeris. The PSD is presented here for μ = 100, 1000 and 5000 MeV/G electrons.

We notice that the third HSS exhibited:

- The most intense and long-lasting energisation of electrons of different μ values, detected by both RBSP and ERG satellites.
- The energisation is more prominent and significantly more persistent for increasing μ values, with μ=5000 MeV/G remaining enhanced until the next HSS arrives.

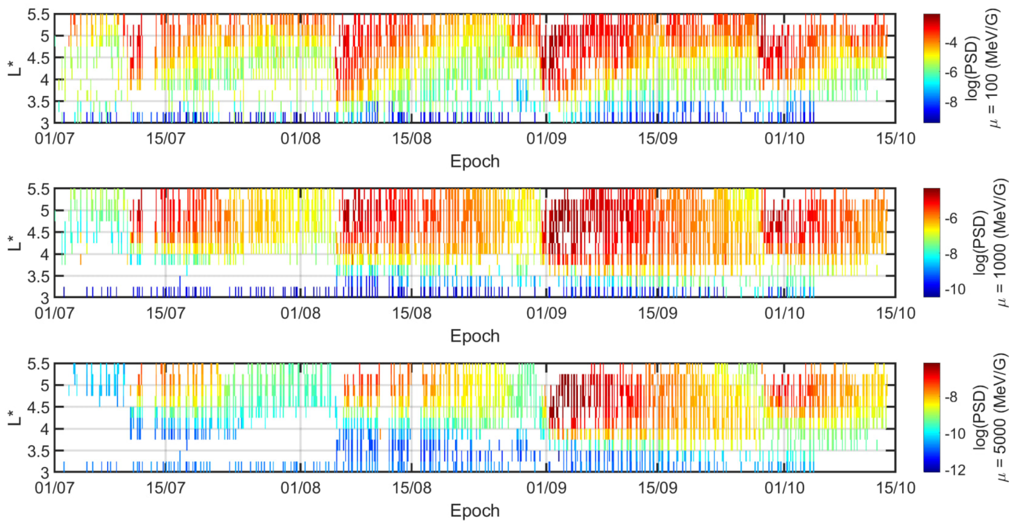

Figure 8. Electron PSD for μ = 100, 1000 and 5000 MeV/G, from combined data of RBSP-A and ERG spacecraft.

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Media sources:

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ABSTRACT

During the second half of 2019, a series of recurring, moderate geomagnetic storms (Dst_{min} ≈ - 70 nT) emerged after a sequence of high-speed solar wind streams (V_{SW} ≥ 600 km/s) impacted the magnetosphere. During one of these storms, intense substorm activity was also recorded (SML ≈ - 2000 nT on August 31 and September 1), as well as a longer-lasting solar wind pressure pulse.

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