On the Statistics of Acceleration and Loss of Relativistic Electrons in the Outer Radiation Belt: A Superposed Epoch Analysis

Christos Katsavrias[1,2], Ioannis A. Daglis[1,2,3] and Wen Li[4]

1. *National and Kapodistrian University of Athens, Department of Physics, Athens, Greece;*
2. *Institute for Accelerating Systems and Applications, Athens, Greece;*
3. *National Observatory of Athens, IAASARS, Penteli, Greece;*
4. *Center for Space Physics, Boston University, Massachusetts, USA*

INTRODUCTION

- After more than two decades of renewed interest on the variability of the outer radiation belt electron population, the mechanisms responsible for the acceleration or loss are well known *[Horne et al., 2005; Shprits et al. 2006]* yet their relative effect is still under investigation.
- *Turner et al. [2013]*, using electron phase space density derived from THEMIS data, showed that of the 53 events under investigation, 58% resulted in enhancement, 17% in depletion and 25% resulted in no significant change.
- *Katsavrias et al. [2015a]* compared two storms to demonstrate that the storm which resulted in enhancement of relativistic electron PSD exhibited similar chorus and Pc5 enhancements both in amplitude and in temporal/spatial range, compared to the one resulted in PSD depletion.
- The possibility that the Dst index is not related to the mechanisms that cause acceleration and loss of the electron population of the outer belt, renders it an inappropriate selection parameter of the studies of electron variability *[Schiller et al., 2014; Katsavrias et al., 2015b]*.
- To that end, this work presents a new approach, by combining both storm and non-storm events. To do that we consider as proxy the maximum compression of the magnetopause instead of the traditional minimum of the Dst index.

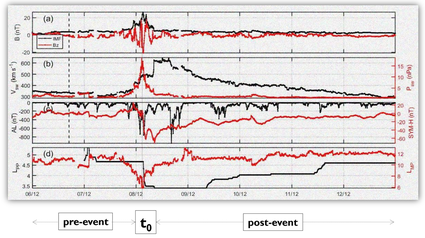
Event Selection

- Average solar wind conditions at least 12 hours before the start of the event:

V_{sw} < 400 km/s	P_{sw} < 3 nPa	SYM-H > -20 nT	AL > -300 nT	-5 < Bz < 5 nT

- 71 events during the RBSP era (9/2012 – 4/2018) spanning the maximum/declining phase of Solar cycle 24.

Figure 1. Example of a selected event (December 6-12, 2013) using solar wind and magnetosphere parameters with 5 minutes resolution. The location of the dayside magnetopause and the average location of the plasmapause based on the models by Shue et al. [1998] and O'Brien et al. [2003], respectively.

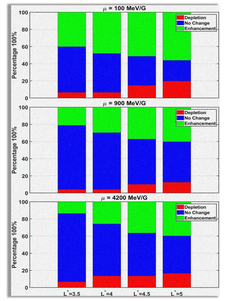


Net Effect Statistics

Enhancements	$PSD_{Post}/PSD_{Pre} \geq 6$
Depletions	$PSD_{Post}/PSD_{Pre} \leq 1/4$
No Change	$1/4 < PSD_{Post}/PSD_{Pre} < 6$

Figure 2. Percentage of event outcome as a function of μ (100, 900 and 4200 MeV/G) and L* (3.5, 4, 4.5 and 5) for near-equatorial mirroring electrons. As shown, the result of each geospace disturbance is μ- and L*-dependent.

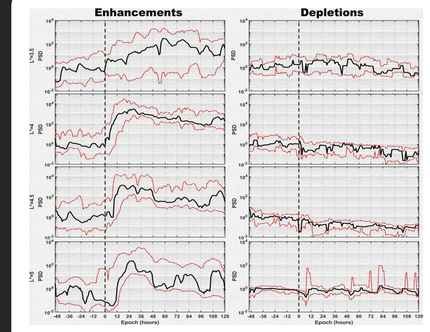
- **20 Events with enhancement of the relativistic (μ = 900 MeV/G) electron population at L*≥4.5**
- **8 Events with depletion of the relativistic (μ = 900 MeV/G) electron population at L*≥4.5**



Seed Electrons (100 MeV/G)

Figure 7. The importance of the intense series of substorm activity is shown in the time evolution of the seed electron population:

- **Enhancement events exhibit clear PSD increases up to three orders of magnitude**, while
- **During depletion events, PSD exhibits intermittent increases and decreases.**



Relativistic (900 MeV/G) And Ultra-relativistic Electrons (4200 MeV/G)

Figure 8 and 9. At higher L-shells and after t_0, we can observe 2 distinct phases:

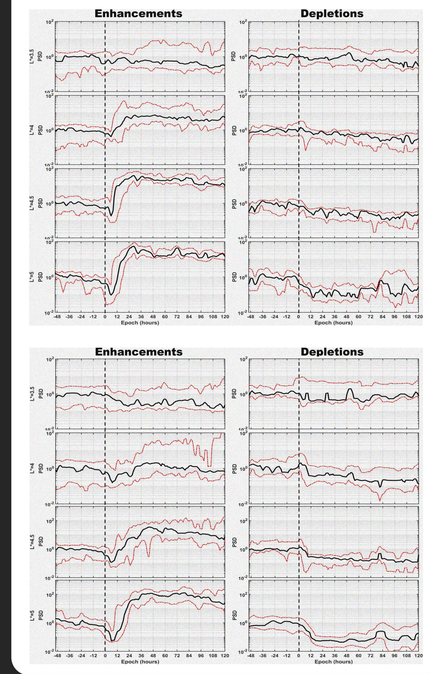
- **Phase 1 (t_0 – t_0+12 hours):**

PSD dropout which coincides with the minimum Lmp and Bz, and the maximum Pc5 power, indicating losses by **combined magnetopause shadowing and outward diffusion driven by Pc5 waves.**

- **Phase 2 (t_0 +12 – t_0+120 hours):**

During enhancement events, relativistic electrons are quickly replenished as the **pronounced and long-lived chorus** accelerate the enhanced seed population.

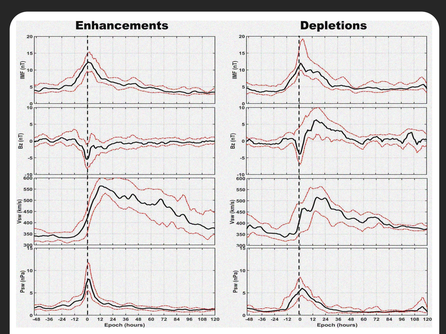
During depletion events, at the absence of significant seed population, **relativistic electrons remain depleted**.



Solar Wind Parameters

Figure 3. Enhancement group is associated with events characterized by:

- **stronger pressure pulses,**
- **higher and long-lasting values of solar wind speed**
- **continuously negative values of the z-component** up to 1.5 day compared to depletion events.

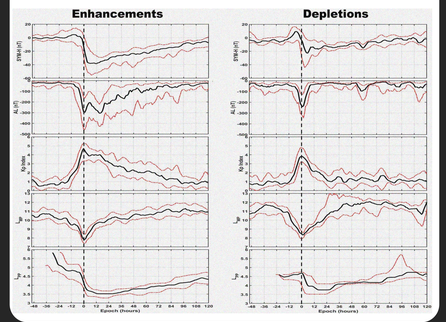


Magnetospheric Parameters

Figure 4. Events that result in relativistic electron enhancements are also associated with:

- **higher levels of magnetospheric activity** as reflected in the SYM-H, Kp and AL indices.
- **larger compressions of both the magnetopause and plasmapause**.

Note that the most pronounced difference between the two event groups occurs in AL index which is a very good proxy of substorm activity.

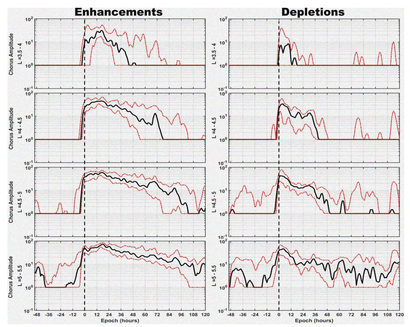


Chorus Amplitude

Figure 5. Chorus amplitude inferred from POES electron (30–100 keV) precipitation *[Li et al., 2013]*.

Following the substorm activity (as indicated by the AL index), enhancement events are associated with:

- **more pronounced and long-lived chorus wave activity**, over a broad L-shell region, compared with depletion events.



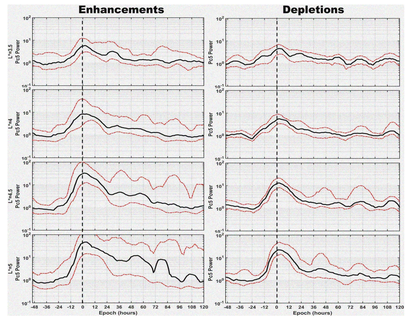
Pc5 Power

Figure 6. Pc5 activity does not exhibit significant difference concerning the maximum power between enhancement and depletion events but exhibits significant differences concerning the duration of enhanced activity (3.5 and 1.5 days after t_0, respectively).

Enhancement events are associated with:

- **longer-lived Pc5 wave activity**, especially at L*>4, compared with depletion events.

Note that there is a remarkable similarity in the time evolution of Kp index and Pc5 power indicating that – even though Kp is a global index – it can be a good proxy for ULF wave activity.



CONCLUSIONS

1. **The number of enhancement events is μ- and L* dependent** (increases with increasing L* but decreases with increasing μ).
2. **Enhancement events** are caused by geospace disturbances with **persistently southward z component of the IMF combined with large and long–lasting values of solar wind speed**.
3. **During enhancement events**, the enhanced reconnection leads to **stronger and long–lasting decrease of SYM-H index** but, most importantly, leads to **intense substorm activity** and thus, **more intense and long–lived chorus activity**. Consequently, enhancement events exhibit **increase of the seed electron PSD**, while depletion events exhibit weaker increases.
4. **Pc5 activity** does not exhibit significant differences concerning the maximum power, but **exhibits significant differences concerning the duration**.
5. **During enhancement events**, the existence of **enhanced seed population and chorus activity can quickly replenish the losses of relativistic electrons** due to combined magnetopause shadowing and outward diffusion.
6. **During depletion events,** the absence of enhanced seed population and chorus activity renders **the combination of magnetopause shadowing and outward diffusion as the dominant loss mechanism**.

REFERENCES

- Horne et al., 2005, Timescale for radiation belt electron acceleration by whistler mode chorus waves, J. Geophys. Res., 110, A03225, doi:10.1029/2004JA010811.
- **Katsavrias et al., 2015a, Concurrent effects of Pc5 and chorus waves on relativistic electron dynamics, Ann. Geophys., 33, 1173-1181, doi:10.5194/angeo-33-1173-2015**
- **Katsavrias et al., 2015b, Nonstorm Loss of Relativistic Electrons in the Outer Radiation Belt, *Geophys. Res. Lett.*, 42, 10,521-10,530, doi:10.1002/2015GL066773.**
- Li, W., et al., (2013), Constructing the global distribution of chorus wave intensity using measurements of electrons by the POES satellites and waves by the Van Allen Probes, Geophys. Res. Lett., 40, doi:10.1002/grl.50920.
- Schiller, Q., et al., (2014), A nonstorm time enhancement of relativistic electrons in the outer radiation belt, Geophys. Res. Lett., 41, 7-12, doi:10.1002/2013GL058485.
- Shprits, Y.Y., et al. (2006), Outward radial diffusion driven by losses at magnetopause, J. Geophys. Res., 111, A11214, doi:10.1029/2006JA011657.
- Turner et al., 2013, On the storm-time evolution of relativistic electron phase space density in Earth's outer radiation belt, J. Geophys. Res., 118, 2196-2212, doi:10.1002/jgra.50151.

Institute of Accelerating Systems and Applications
University of Athens

HELLENIC REPUBLIC
National and Kapodistrian University of Athens
EST. 1837