Ultra-relativistic (>~3 MeV) Electron Flux Enhancements in the Van Allen Belts

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Abstract

The Van Allen Belts are torus-shaped regions of energetic particles that surround the Earth. Understanding the effects of solar wind structures on the radiation belt particles is of both scientific interests and practical needs since high energy electrons can harm sensitive electronics and astronauts in orbit. Coronal mass ejections (CME) and corotating interaction regions (CIR) are two primary types of solar activity that cause geomagnetic storms and thus affect the Van Allen Belts. In this study, the relationship between geomagnetic storms with different solar wind drivers and ultra-relativistic electron flux variations was inspected using data from the Van Allen Probes. Using solar wind data from 2012 to 2018, 27 CME-driven storms and 28 CIR-driven storms were identified. Superposed epoch analysis was performed on ultra-relativistic electron fluxes during CME/CIR-driven storms, respectively, using data from Relativistic Electron Proton Telescope (REPT) on the Van Allen Probes. The preliminary results show deeper and faster flux enhancements of ultra-relativistic electrons in CME-driven storms compared to CIR-driven storms, which is consistent with previous studies on the electrons with lower energies. Significant electron flux enhancement occurs approximately two days after the arrival of CIR, and approximately one day after a CME arrival for 3 MeV to 6 MeV electrons. These results also show that for CME-driven events, there is a clear electron flux enhancement in the 7.7 MeV and 6.3 MeV electron energy channels. For CIR-driven events, there is a less dramatic increase. Further analysis of the enhancement events and non-enhancement events of ultra-relativistic electrons during CME/CIR-driven storms using the REPT data provides insight into the effects of different solar wind drivers on the acceleration/loss of ultra-relativistic electrons in the radiation belts.

Methods and Procedure

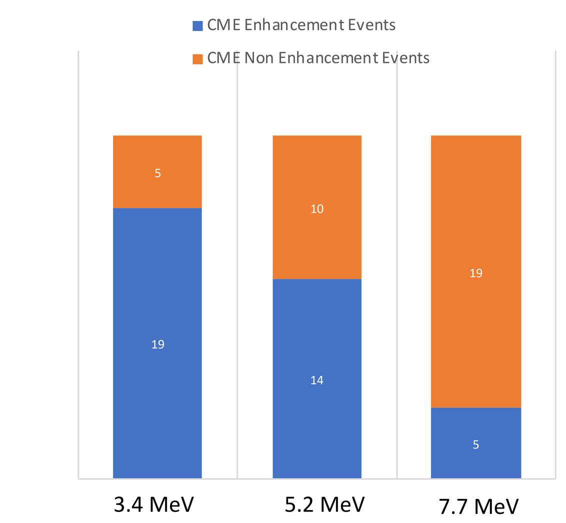
Using the D_{st} Index, dates of geomagnetic storms with a D_{st} less than -50 nT were flagged as a geomagnetic storm. By observing the solar wind parameters surrounding these storms, and using known criteria for distinguishing CME/CIR storms, the dates of CME and CIR-driven storms were compiled into lists. From these dates, superposed epoch analysis was performed on both the solar wind parameters as well as REPT's differential energy electron data. The results of these techniques are presented in the "CME vs CIR" section.

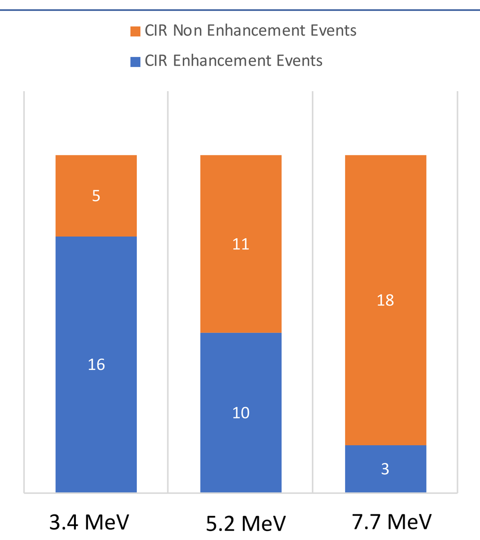
To further study how each varying energy channels responds to CME-driven and CIR-driven storms, Superposed Epoch Analysis was performed when enhancement occurred in the 3.4MeV, 5.2MeV, and 7.7 MeV energy channels. These results are located in the "Enhancement in Varying Energy Channels" section.

To see how solar wind parameters and enhancement/non-enhancement events are correlated, Superposed Epoch Analysis was performed on all dates where enhancement occurs in the 3.4 MeV energy channel, as well as all storms that did not induce enhancement in 3.4 MeV channel, but did induce enhancement in lower energy channels. These results are in the "Difference in Enhancement/Non-enhancement" section.

Number of Events

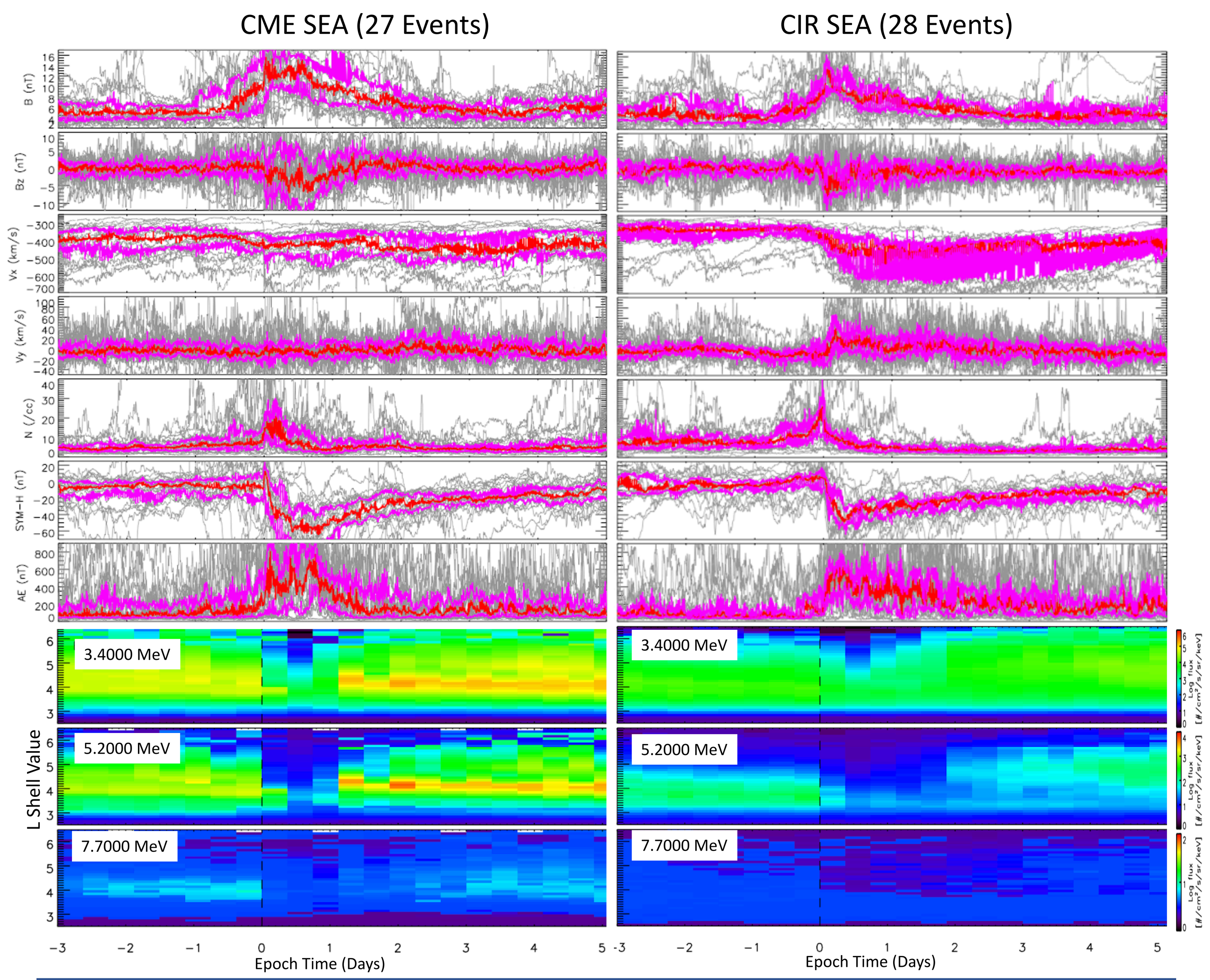
Below are graphs of how many CME/CIR events correlate with enhancement/non-enhancement for each energy channel. Enhancement is defined as the post-storm fluxes increased by at least a factor of 2 compared to pre-storm fluxes at an L range larger than 0.5. As the energy channel increases, the number of enhancement events decreases. This is because during a single, isolated storm when high energy enhancement occurs, lower energy enhancement often also occurs.





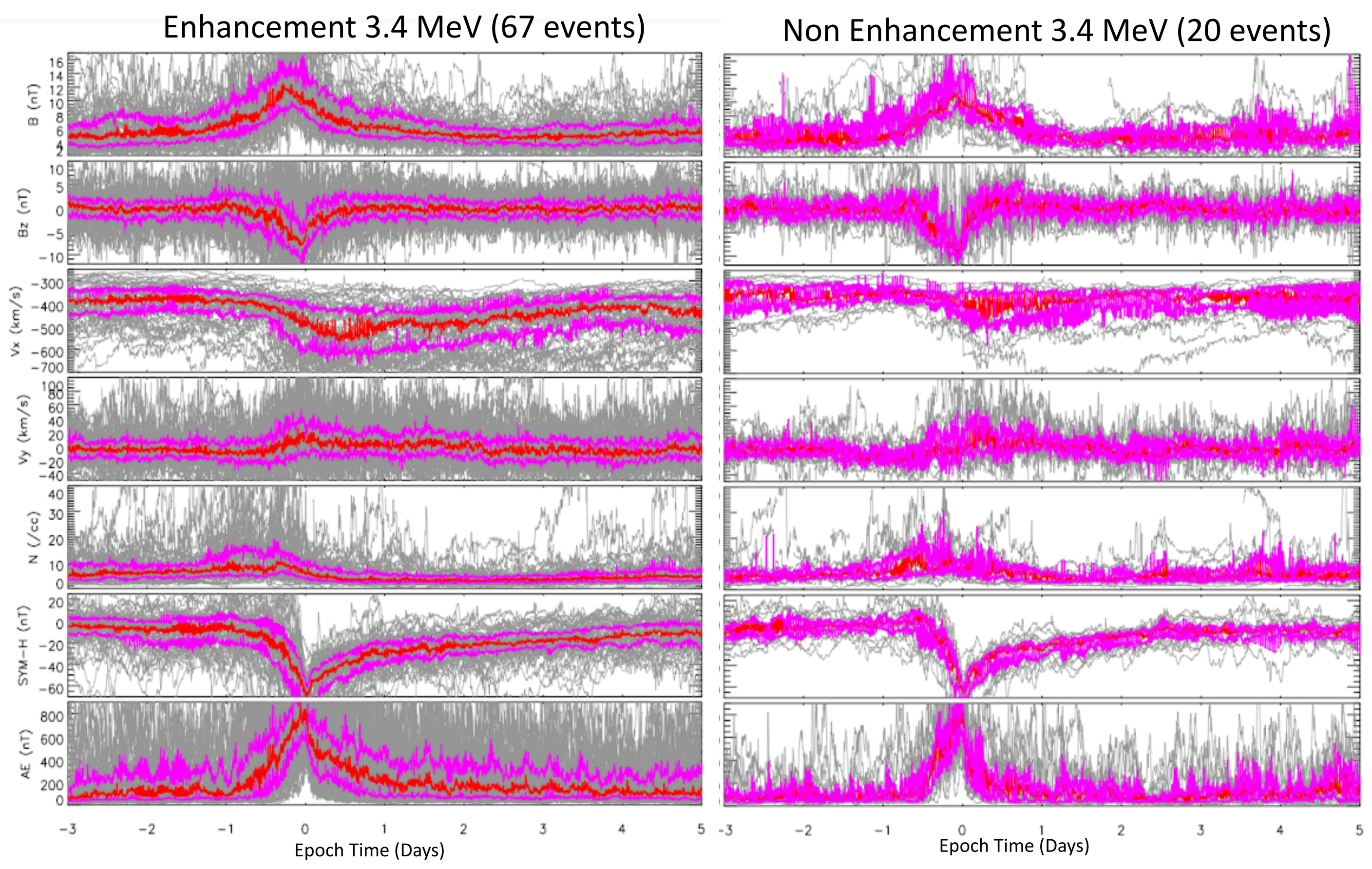
CME vs CIR

Below are figures of Superposed Epoch Analysis of CME/CIR and their corresponding solar wind parameters, and their respective energy level fluxes at the 3.4 MeV, 5.4 MeV, and 7.7 MeV electron energy channels. Notice how the CIR V_y is bimodal and the CIR V_x is stronger than the CME V_x. Also notice that the electron flux enhancements are much deeper for CME events at all energy levels. The time it takes for enhancement to occur is longer for CIR-driven events than CME-driven events.



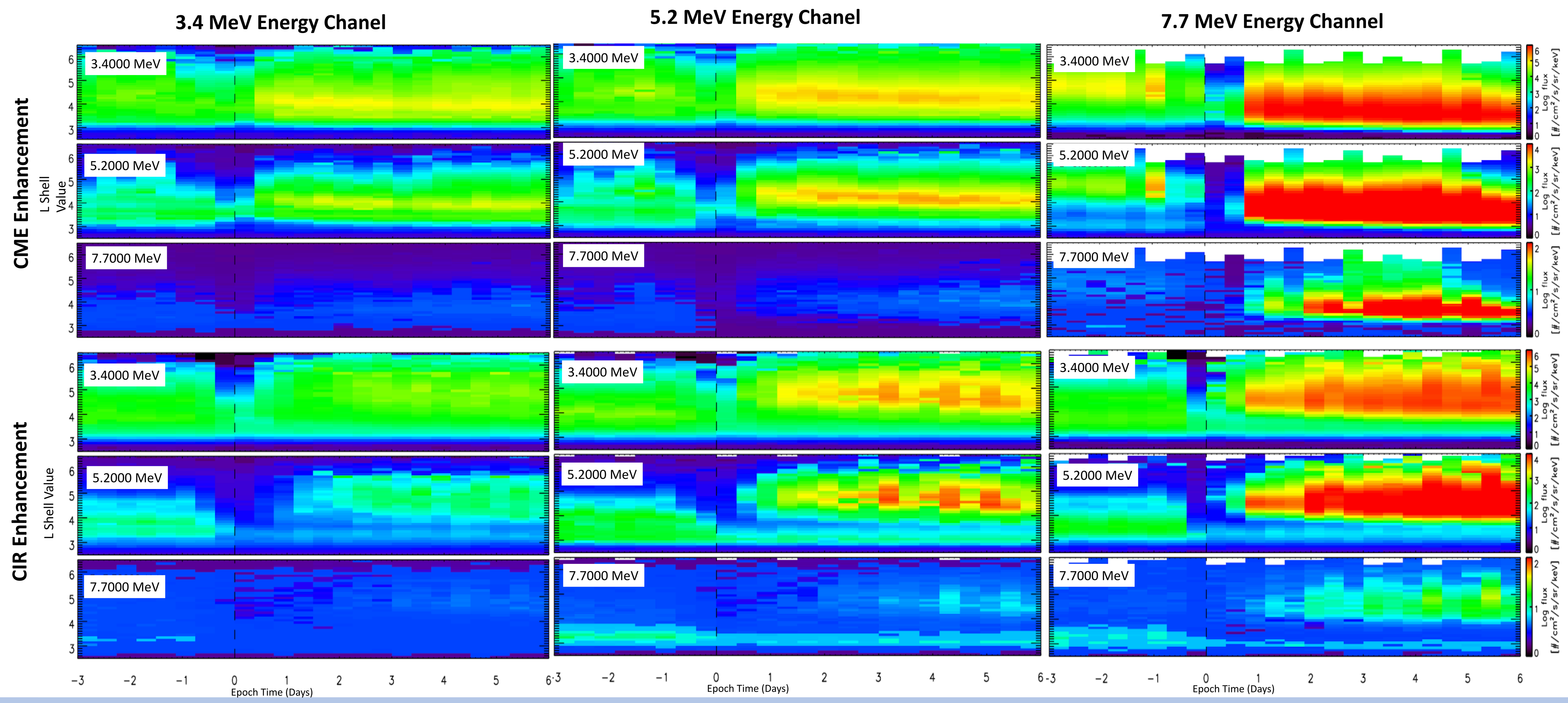
Difference in Enhancement/ Non-Enhancement

Solar wind speed is greater and proton density (N) is lower for enhancement events at the 3.4 MeV energy channel.



Enhancement in Varying Energy Channels

These graphs display the flux density before and after CME/CIR enhancement events in each energy channel. The higher the energy channel, the more deep the enhancement in lower energy levels. The time it takes for enhancement to occur changes from the storm type as well as the energy channel where flux enhancement occurs.



Conclusions

1. Higher solar wind speed results in higher probability for enhancement of ultra-relativistic electrons in the radiation belts.
2. Enhancement in higher energies usually means enhancement in lower energies.
3. Enhancement events are deeper and quicker for CME-driven events than CIR-driven events.
4. CIR flux enhancement occurs at higher L shell values than pre-flux enhancement and CME flux enhancement occurs at lower L shell values than pre-flux enhancement.

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References

1. Shen et al. (2012)
2. Zhao et al. (2019)

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