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Relativistic protons' (>20 MeV) observation deep into the inner magnetosphere

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Abstract

Solar wind particles and the interaction of the Earth's magnetic field with the interplanetary drivers greatly affect the evolution of the inner magnetospheric particle. However, the relativistic protons are those uniquely trapped particles in the Earth's magnetosphere that has extremely high energies but much more stable than electrons. For each geomagnetic storm with Sym-H<-50 nT, we investigated that there is no observable proton flux, measured by REPT instrument on board Van Allen probes, beyond L=3 [1]. However, after the launch of Van Allen probes era in 2012, the first strongest solar flare of solar cycle 24 erupted with X9.3 class that accompanied the most energetic proton event, since past one decade. During this event, Van Allen probes made a very important and crucial observations of these most energetic radiation belt protons, deep into the inner magnetosphere. During 10-12 Sep 2017, Van Allen probes recorded the highest proton flux since its launch. It increased by several order that persisted for ~2 days. In this paper we importantly focused on this rare event by studying the extent of proton flux enhancement and its penetration deep into the inner magnetosphere. Moreover, we analyzed the related mechanism for the proton flux injection and loss during September 2017.

1. Introduction

The radiation belt electron and protons evolve with the changing solar wind and geomagnetic conditions. Although the proton radiation belt is measured by many spacecraft its dynamics and behavior is less known. The proton flux decreases with the increasing L-value. Relativistic electron and protons trapped below L~2 have extremely high energies and are relatively invariable than the electrons. The relative stability of the relativistic protons, makes it difficult to analyze the spatial and temporal distribution of relativistic protons using only a single spacecraft.

For event based studies a multi-spacecraft observations would provide much information. Such approaches are always useful for understanding the behavior of particle in the various region of the Earth's magnetosphere. Previously, the studies involving two or more spacecraft located within or outside the Earth's magnetosphere has concluded that the enhancement observed in the Earth's magnetosphere originates from the near-Earth magnetospheric phenomenon [2,3].

The high energy protons observed during Solar Proton Events (SPEs) are transported deep into the Earth's magnetosphere giving rise to another proton belt with higher energies [4].

This paper is about >20 MeV energy proton flux enhancement observed by RBSP during the September 2017 geomagnetic storm. This was the largest proton flux ever observed by the spacecraft since its launch. However, the lunch of Van Allen probes provides a key particle observations, covering precise energy ranges, in the desired region of the Earth's inner magnetosphere.

2. Data

Energetic particle flux from four different spacecrafts were used for this studies. This group of satellites includes two Van Allen Probes (RBSP-A, RBSP-B), Advanced Composition Explorer (ACE), WIND and GOES 15. ACE and WIND gives the proton flux of various energy levels at Earth's L1 point. On the other hand, RBSP and GOES-15 satellite provides proton distribution in the near-equatorial inner magnetosphere.

The solar wind plasma parameters like solar wind velocity (Vsw), solar wind dynamic pressure (Psw) and Interplanetary Magnetic field (IMF) Bz are fetched with one minute resolution from the omni database. Building of one minute dataset at the bow shock nose is obtained by adding the dataset from ACE, WIND, IMP and Geotail (https://omniweb.gsfc.nasa.gov). On the other hand, Sym-H is obtained from World Data Center for Geomagnetism, Kyoto (http://wdc.kugi.kyoto-u.ac.jp/aeasy/). It is a high resolution version of the Dst-index, giving one minute average of the Earth's H-component variations [5].

3. Analysis and Results

>20 MeV proton flux measured by RBSP-REPT

RBSP-REPT instrument measured the proton flux with energies >20 MeV since 2012. For each geomagnetic storm with Sym-H<-50 nT, we investigated that there is no observable proton flux, measured by REPT, beyond L=3 [1]. However, during the moderately intense geomagnetic storm of 8 Sep 2017, a sudden enhancement of >20 MeV proton flux was observed. Figure 1(a, b) gives the Energy-Time (E-T) spectrogram of proton flux measured by RBSP-A and RBSP-B in the energy range of 20 MeV to 200 MeV for 4-15 Sep 2017. Figure 1(c) shows the GOES15 X-Ray flux for two different wavelengths: a longer wavelength of 0.05 to 0.4 nm and a shorter wavelength of 0.1 to 0.8 nm. Figure 1(d, e, f) gives the solar wind parameters like Vsw, Psw and IMF Bz. The lowest panel (g) gives the Sym-H index with Sym-H minimum -146 nT at 0107 UT on 8 Sep 2017.

As shown in Figure 1(a, b), on 7 Sep 2017, a slight increase in proton flux was observed by RBSP-A and RBSP-B in the energy range of 21.25 MeV - 27.6 MeV and continued for ~24 hours in both the probes. On the other hand, during the recovery phase of the geomagnetic storm, even stronger enhancement of proton flux at L=5 in the energy range of 21.25 MeV - 102.6 MeV was observed by Probe-A and B on 10 Sep 2017. Figure 1(c) shows two X-ray flux peaks measured by GOES15 at 0.1-0.8 nm wavelength on 6 sep 2017 12:02 UT and 10 sep 2017 16:06 UT with the corresponding fluxes 9.41×10^{-4} W/m^2 and 8.301×10^{-2} W/m^2, respectively. However, the interplanetary parameters shown in Figure 1(d, e, f) attribute to the changes in the Sym-H component Figure 1(g).

In this paper we studied the extent of proton flux enhancement during the September 2017 SEP event. We studied that the flux increased by two to three order on 7 Sep 2017 and 10-12 Sep 2017. These observations are verified from ACE and WIND spacecraft and found that 2-102.6 MeV energy band was greatly affected. Moreover, we separately studied the extent of proton access deep into the inner magnetosphere. The results can be visually observed from Figure 2, but is quantified and will be presented at the conference.

4. Figures

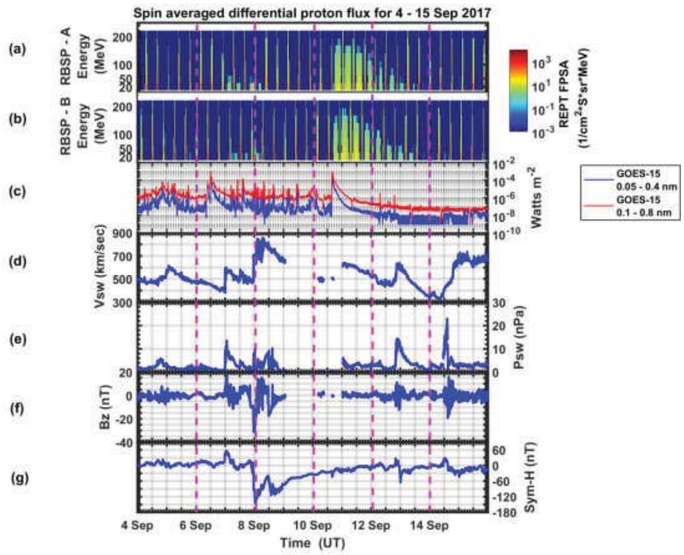

Figure 1. The Energy-Time (E-T) spectrogram of proton flux measured by (a) RBSP-A and (b) RBSP-B in the energy range of 20 MeV to 200 MeV for 4-15 Sep 2017. Panel (c) shows the GOES15 X-Ray flux for two different wavelengths: a longer wavelength of 0.05 to 0.4 nm and a shorter wavelength of 0.1 to 0.8 nm. Panel (d, e, f) gives the solar wind parameters like Vsw, Psw and IMF Bz. The lowest panel (g) gives the Sym-H index with Sym-H minimum.

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6. References

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