30TH INTERNATIONAL COSMIC RAY CONFERENCE

Efects of Coronal Mass Ejections on the Long Term Cosmic Ray Modulation

ALEJANDRO LARA[1] AND ROGELIO CABALLERO-LÓPEZ[1]
[1] *Instituto de Geofísica, Universidad Nacional Autónoma de México*
alara@geofisica.unam.mx

Abstract: Recently we have proposed that the long term solar modulation of galactic cosmic rays (CR) is influenced by coronal mass eyection (CME) activity. In this work, we analyze the effect of CMEs number and latitudinal changes on the CR flux during positive and negative magnetic cycles. For CME data, we use both, recent observations by the Large Angle and Spectrometric Coronagraph (LASCO) experiment on board of SOHO and past observations by Solar Maximum Mission (SMM) and Solarwind spacecrafts. For CR we use data from IMP-8 and Voyager 1/2 spacecrafts. We discuss our results in terms of the magnetic irregularities transported by CMEs in to the heliosphere.

Introduction

The long term modulation of Galactic Cosmic Rays (GCR) due to solar activity has been known since almost half century ago [3]. Many mechanisms have been proposed to explain the decreasing GCR flux in the inner heliosphere (see [1] and references therein), when the solar activity increases, during the ascending phase of the eleven year solar cycle and the corresponding increase of GCR flux during the descending phase of the cycle.

Recently ([4], here after paper 1), we have studied coronal mass ejections (CMEs) as the agent which is transporting the solar activity information, in form of magnetic perturbations, to the outer heliosphere. We proposed that is not only the the total number of CMEs but also the changes in the CME latitude are very important for the GCR modulation. In paper 1, we studied the GCR - CME relationship using both Climax and IMP8 GCR data and Large Angle and Spectrometric Coronagraph Experiment (LASCO) on board of the Solar and Heliospheric Observatory (SOHO) spacecraft. We found a very good anti-correlation between high latitude CME activity and GCR flux during the ascending phase of solar cycle 23, which was positive (qA ¿ 0) cycle. Based on these findings, we predicted that during negative (qa ¡ 0) cycles the GCR flux will be modulated (at least during the ascending phase of the solar cycle) by low latitude CMEs, whereas for positive cycles the modulation will be trough high latitude CMEs. In order to test this idea, in this work we use CME available for solar cycle 21, 22 and 23 from different space craft observatories and compare the CME total number and latitude changes against the GCR flux measured by IMP-8 spacecraft.

data

We use data form:

- Solarwind coronograph on board of the P78-1 satellite [7] during the ascending phase of cycle 21 (qA ¿ 0). From 1979 to 1985.
- The High Altitude Observatory Coronograph/Polarimeter on board the Solar Maximum Mission [5] during part of cycle 22 (qA ¡ 0). From 1984 to 1989.
- The Large Angle Spectroscopic Coronagraph (LASCO) on board of SOHO ([2]) during major part of cycle 23 (qA ¿ 0). From 1996 to 2006.

It is important to note that the sensitivity of these experiments varies highly, making difficult a direct comparison between them. Also, in this study we are no taking into account the duty cycle of the instruments.

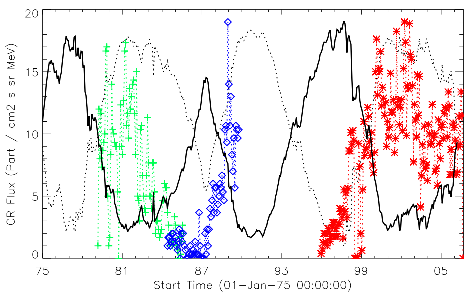

Figure 1: GCR (continuous line) and CMEs observed by Solarwind (plus symbols) SMM (diamonds) and LASCO (stars) during solar cycles 21, 22 and 23. CME number is scaled to fit the GCR flux range.

The GCR data comes from IMP-8 Goddard Medium Energy (GME) Experiment, in this case we use proton flux in the 121 - 229 MeV MeV energy range.

Figure 1 shows the IMP-8 proton flux direct (continuous line) and inverted (dotted line). Overplotted and scaled to fit the GCR flux range, is the number of CMEs measured by Solarwind (plus symbols), SMM (diamonds) and LASCO (stars).

analysis

cycle 21

Figure 2 shows the CME - GCR relationship during solar cycle 21. Similar to Fig. 1 we have plotted the direct (continuous line) and inverse (dotted line) GCR flux, plus symbols denote the total (top panel), low latitude (middle panel) and high latitude (bottom panel) number of CMEs observed by solarwind. Unfortunately, Solarwind started observations on 1979, on the ascending phase of the cycle. This makes difficult to compare the effects of CMEs on the decreasing phase of the GCR flux.

Cycle 22

Figure 3 shows the IMP-8 proton flux during part of cycle 22 when SMM was in operation. Again in this case the data covers only part of the cycle,

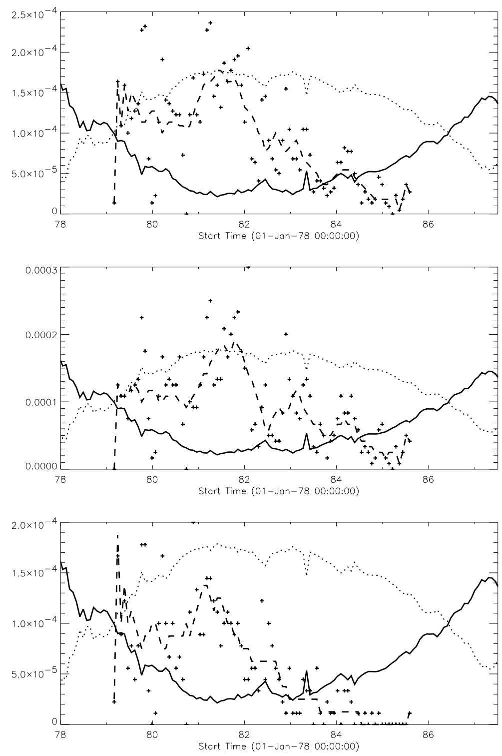

Figure 2: IMP - 8 proton flux (120 - 230 MeV) during solar cycle 21. Plus symbols, from top to bottom represent the total, low latitude and high latitude number of CMEs observed by Solwind

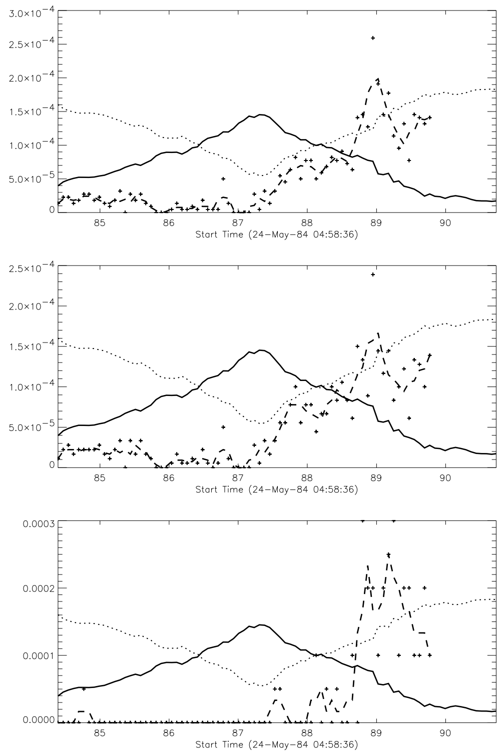

Figure 3: Same as Figure 2 but for cycle 22. The CME data was observed by SMM spacecraft.

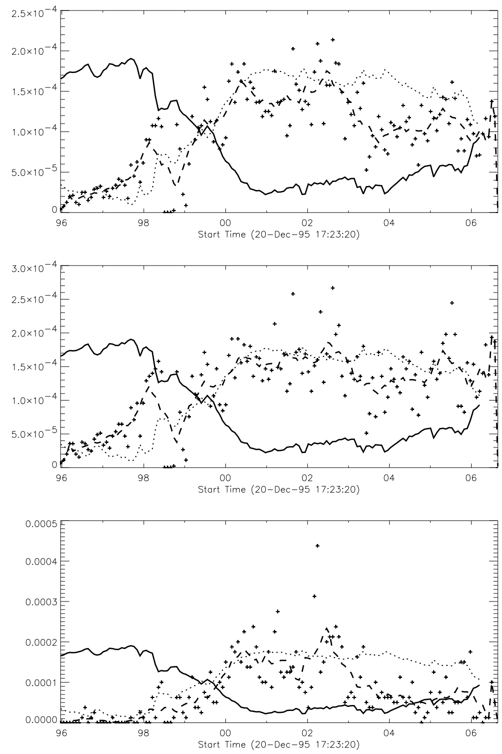

Figure 4: Same as Fig 2 but for solar cycle 23, in this case, CME data comes from LASCO experiment.

Fortunately we have the ascending part of the solar cycle. The top panel (all CMEs) show a similar behavior between the CME number increase and the decreasing GCR flux. It is necessary a deep analysis, although it is clear that the low latitude CME number is better anti-correlated with the GCR flux than the high latitude number. In this case, low latitude CME activity started early in 1987 few months before than the GCR decreasing phase. Whereas high latitude CME activity seems to start towards the end of 1988.

Cycle 23

In this case CME data is available for the whole cycle, except for two major data gaps during 1998 and 1999 (Figure 4). As we stated in Paper 1, the number of low latitude CMEs started early in 1996, whereas the GCR flux still unaffected. On the other hand high latitude CMEs activity started in 1998 at the same time that the GCR long term modulation.

Discussion and Conclusions

This preliminary analysis of the GCR flux and CME number relationship, shows that CMEs play a fundamental role in the eleven year GCR modulation. Even more, we show that this modulation is carried out by high latitude CMEs during positive (qA ¿ 0) cycles and by low latitude CMEs during negative (qA ¡ 0) cycles. This finding is in agreement with the GCR transport theory, which states that the inflow of GCRs depends on the solar magnetic polarity. During $qA > 0$ epoch, (where the heliospheric magnetic field is directed outward in the north polar region and inward in the south polar region, as in the first half of cycle 23), the GCRs drift inward from the polar regions to the equatorial plane and then outward along the HCS; during $qA < 0$ epochs, the drift is inward through the HCS, from the equatorial plane to the poles (see figure 2 in [6]). Therefore, the effect of CMEs on the GCR modulation must be different depending on the CME latitude and qA sign during the cycle.

We note an interesting behavior by analyzing Figure 1 (or Figures 2 and 4): The CME - GCR flux seems to be well correlated during the ascending phase and the first maximum of the cycle. After that there is no apparent relationship between them.

Acknowledgments

This work was supported by , UNAM-DGAPA Grants IN18906 and IN106105.

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