

Cosmic Ray Events related to Solar Activity Recorded at the Athens Neutron Monitor Station for the Period 2000 – 2003

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Abstract

In this work a complete study of 359 solar flares, 111 Halo CMEs and 45 Partial Halo events occurred from November 2000 to November 2003, is considered. This time period characterized by an unexpected activity of the Sun, was divided into 27-day intervals starting from Bartels Rotation No 2284(14.10.2000) to No 2324(25.11.2003), generating diagrams of the cosmic ray intensity data recorded at the Athens Neutron Monitor Station. This station operates at an altitude of 260m and cut-off rigidity 8.53GV and provides high-resolution data in real-time to the Internet. On these qualitative data presented for first time, a mapping of all available solar and interplanetary events, such as solar flares with importance C, M and X, coronal mass ejections (Halo and Partial) etc. was done. As we are going down from the solar maximum to the declining phase of the current cycle a statistical overview of the corresponding relationship among these phenomena, the significant percentage of the connection of Halo CMEs and solar flares and the respective connection to the Forbush effects on yearly and monthly basis are discussed. The role of extreme solar events occurred in March-April 2001 and in October-November 2003 are also discussed. Obtained results may be useful for prediction of transient solar events and space weather forecasting.

Introduction

As the sun is the driver of Space weather, solar events such as solar flares, coronal mass ejections etc. are close related to the Forbush effects recorded at the ground based Neutron Monitor Stations. There are numerous indications that natural solar variability-driven time variations of the Earth's magnetic field can be hazardous in relation to health and safety.

• A solar flare (SF) is defined as a sudden, rapid, and intense variation in brightness. It occurs when magnetic energy that has built up in the solar atmosphere is suddenly released.

Figure 1: Solar Flare occurred at 28/10/2003

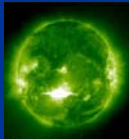
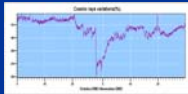


Figure 2: Typical CME



• Coronal Mass Ejections (CMEs) are plasma eruptions from the solar atmosphere involving previously closed regions which are expelled into the interplanetary medium.

Figure 3: A consequence of great Forbush decreases occurred at Oct./Nov. 2003



• Forbush decrease (FD) is a heliospheric phenomenon which is caused in the cosmic rays (CR) by solar wind disturbances, which - in their turn - are caused by processes of the Sun

In this work a brief presentation of the relation between solar flares (SF), Coronal Mass Ejections (CMEs) and Forbush decreases (FD) recorded at the Athens Neutron Monitor Station for the time period 2000 to 2003 is outlined. This examined period covering forty Bartels Rotations, from BR2284 to BR2324 gives very interesting results on occurred extreme events.

Athens Neutron Monitor Station

Cosmic ray measurements in Athens (37.58°N, 23.47°E) initiated in November 2000 with a standard 6NM-64 neutron monitor. The measurements of the station are being elaborated automatically in order to be compatible to other stations data because of the necessity to compare a number of high rigidity stations in a good quality data which is required for a detailed study of CR variations and space weather conditions. The resolution of the measurements reaches as far as one second - which is uniquely worldwide.

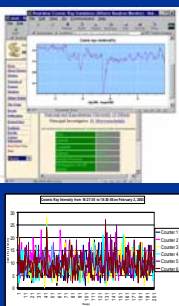


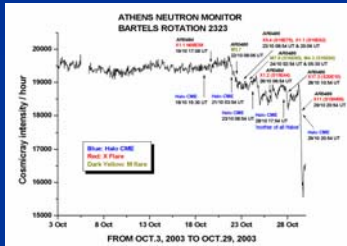
Figure 4: Recent extreme events recorded at the Athens Neutron Monitor Station - July/August 2004. (upper panel) and 1sec High Resolution Data (lower panel)

Data Sources

Athens NM data are available in the on-line database at: <http://cosmicray.phys.uoa.gr>
Preliminary CME Lists of the U.S. Naval Research Laboratory (NRL) on the Large Angle and Spectrometric Coronagraph (LASCO) are used. These lists represent a subset of the final LASCO dataset and can be accessed through the web at the site: <http://lasco-www.nrl.navy.mil/>. This last catalog included a significant number of flare events taken from <http://www.sec.noaa.gov/today.html> and are confirmed at <http://hea-www.harvard.edu/SSXG/kathy/flares>

Mapping of Solar Activity on CR data

On the constructed diagrams all available data, such as: time of first observation, date the event occurred and its co-ordinates are recorded. In this way an overall statistical picture of the relation between CMEs, Flares and Forbush decreases (FD) is obtained. Cosmic ray intensity as recorded from Athens Neutron Monitor for the extraordinary periods 4/BR2284 to 23/BR2324, 30/BR2323, 30/BR2324, 10/2325, BR2324 and 29/Mar to 23/Apr. 2001 (BR 2289) are shown.



Statistical Analysis

A detailed statistical analysis of our data creating histograms of Halo CMEs, Forbush decreases and flares with significance > M and < M is performed. Our prospective goal is to generate a clear image of the intense events occurred at the declining phase of solar activity. The expected peaks denoted at the histograms underneath for BR 2289, BR 2323 & BR 2324.

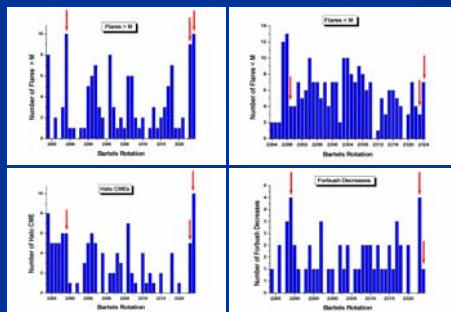


Figure 6: Histograms of Solar events for the three-year period 2000 - 2003

Solar/Heliospheric Events Occurrence

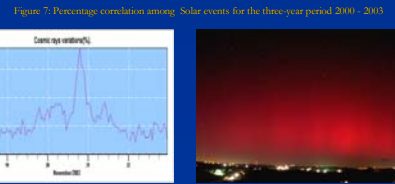
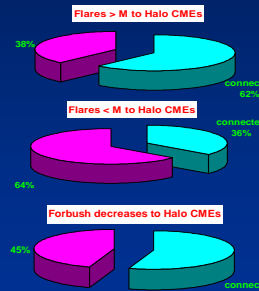


Figure 8: The big magnetic storm and the aurora in Athens on November 20, 2003

Which days within a 27-day interval does the Sun prefer?

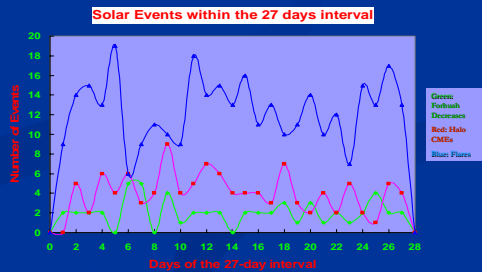


Figure 9: Diagram of all solar events occurred, within a 27-day interval

Results

The detailed analysis of the CR data of the Athens Neutron Monitor Station during the characterized time period 2000 – 2003 in relation to the solar events leads us to the following results:

- ➔ A number of 359 flares and 111 Halo CMEs occurred within the studied period, caused 56 Forbush decreases (52 FDs and 4 Ds) of the cosmic ray intensity on the ground based NMs.
- ➔ During this period two extreme bursts of solar activity in March-April 2001 and October-November 2003 were recorded. Outstanding events distinguished by their magnitude and unusual peculiarities were observed. In particular:
 - Three Ground Level Events in one week at the end of October 2003! (See Figure 6)
 - Aurora was visible even from lower latitudes. It was very clear at Greece on the 20th of November. (See Figure 8)
 - One of the most astonishing Halo CMEs took place on the 28th of October 2003 and it was actually called: 'Mother of all Halos'. It provided a major GLE called 'Greek Effect' and Forbush decreases of 21% as recorded at Athens NM (See Figure 5)

➔ It is noteworthy that an approximately 24-hours window from the occurrence of a SF to the occurrence of a Halo CME is denoted. As expected Forbush decreases usually appear almost one day after the appearance of a Halo CME. Preferable days of these events within the Bartels rotation seem not to exist.

References

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