Unusually extreme cosmic ray events in July 2005

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Abstract

During the second half of July 2005 extreme solar and interplanetary events with interesting peculiarities were recorded. The Sun was rather active and in a total of 35 C-class, 13 M-class and 1 X-class solar flares, as well as five Halo Coronal Mass Ejections (CMEs) were produced from a single active region (NOAA 786), in the 8-days time period, from 11 to 18 July. Moreover, a series of Forbush effects took place from 12 July causing a decrease in cosmic ray (CR) intensity of about 2%, by the 16 July. As a result, the Athens Neutron Monitor Data Processing Center (ANMODAP) detected an intensive Forbush decrease (FD) of cosmic rays, on the 16th of July, observed by the majority of the neutron monitors worldwide.

A sharp enhancement of cosmic ray intensity occurred right after the main phase of the FD on 16 July, was followed by a second decrease within less than 12 hours. The peculiarity of this event owes to the fact that it does not comprise a ground level enhancement of solar cosmic rays neither a geomagnetic effect in cosmic rays. This event appear to be caused by some special structure of interplanetary disturbances in the inner heliosphere at that time period when the Earth crossed a periphery of a giant Forbush effect started in the western part of the heliosphere after the flare on 14 July. It is important to note that on the 18 July, there was a good sized sunspot at the far side of the Sun, whereas its Earth side was spotless. This sunspot had already been traced by the 14 of July and had played a significant role to the solar activity of the previous days.

An analysis of all available neutron monitor and satellite data concerning these events as well as a confirmation of our preliminary results by the onset process of the ANMODAP Center is carried out.

Keywords: Cosmic ray intensity, Neutron Monitors, shock waves, solar flares

1. Introduction

A number of extreme events characterized by rather peculiar properties have recently taken place, in a time period very close to the minimum of the 23rd cycle of solar activity (*Eroshenko et al., 2004; Belov et al., 2005; Plainaki et al., 2005*). Solar flares (SF) and coronal mass ejections (CMEs) produced large variations in cosmic ray (CR) intensity. Over the last years a lot of attempts to explore the relation between these phenomena as well as their impact on cosmic rays (e.g. Forbush decreases (FD), Ground Level Enhancements) have been made (*Hundhausen et al., 1999; Harisson,* *1995; Cane, 2000*). The offspring of these analyses is that solar extreme events influence cosmic rays in a dynamic way. Whenever an intense or/and unusual decrease or increase in cosmic rays is recorded, it is essential to analyse the background of the event regarding solar and geomagnetic activity as well as cosmic ray activity and anisotropy (*Belov et al., 2001).*

In this work analogous analysis has been made for the extreme events occurred in the mid of July 2005. Specifically, rather intense Forbush decrease (~8%) was detected at neutron monitors all over the world on the 16 July 2005. It started some hours before arrival of a weak shock associated with a CME from 14 July. Soon after the main phase, a sharp enhancement of cosmic ray intensity followed up, which was continued by a second large decrease, within less than 12 hours, in many neutron monitors. It is a rather peculiar event, as it is not a ground level enhancement of solar cosmic rays, and not a geomagnetic effect in cosmic rays.

The analysis of all available data on July 2005 revealed rather unusual events. Despite the main flares occurred on the western portion of disk the interplanetary space near Earth was not strongly disturbed this period. Solar wind velocity was limited in ~500 km/s and the Interplanetary Magnetic Field (IMF) intensity was ranged within 15 nT. Geomagnetic activity was also relatively quiet, Kp index did not exceed 5, the lowest Dst index was ~-70, and there was no strong shock (Sudden Storm Commencement - SCC). . The event was also characterized by unusually high anisotropy of cosmic rays (~7-8%), especially of the equatorial component, with a direction to the western source of this anisotropy.

From all available data an effort is made to acknowledge all possible causes that can lead to such kind of events. Proposed explanation of them could be of great scientific interest because such events of July 2005 are one of kind events that never before have been revealed.

2. *Solar activity*

It is characteristic that throughout one week (from 11 to 18 July) solar activity ranged from low to very active. Especially low levels occurred at the 11, 15 and 17 July while high levels took place on the 14 and 16 of this month. Sunspots number decreased until a blank Sun revealed on the 17 July as it is illustrated in figure 1. The blank Sun remained for a number of days until the 22nd of this month.

In particular on the 12th of July, a C8.3 flare occurred and followed by a faint partial Halo CME. Later on the same day two M1.0 flares were produced. A more complex with long duration M1.5 flare occurred at 12:47 UT was associated with a bright partial halo CME that was mostly directed westward. In the next day, 13 July, two halo CMEs occurred in association with two solar flares. The first CME was visible at 03:06 UT, had a speed of 700 km/s and accompanied M1.1 flare which took place at 02:35 UT. The second one is associated with a significant long duration M5.0 flare. The CME was seen at 14:30 UT and had a speed of 1420 km/s. The events triggered the proton and electron fluxes that increased gradually.

The active region 786 continued its activity on 14 July to be located around the limb, by producing two major events. Firstly an M9.1 flare peaked at 07:25 UT with an associating CME which was observed by LASCO imagery. The bright CME was first visible at 06:54 UT. A considerably, more powerful, long duration X1.2 flare occurred later at the same day. It started at 10:16 UT. The high-energy fluxes rose above their threshold and a very bright and fast (~ 1430 km/s) halo CME was visible at 10:54 UT. None of the blasts were Earth directed, nevertheless, Earth's magnetic

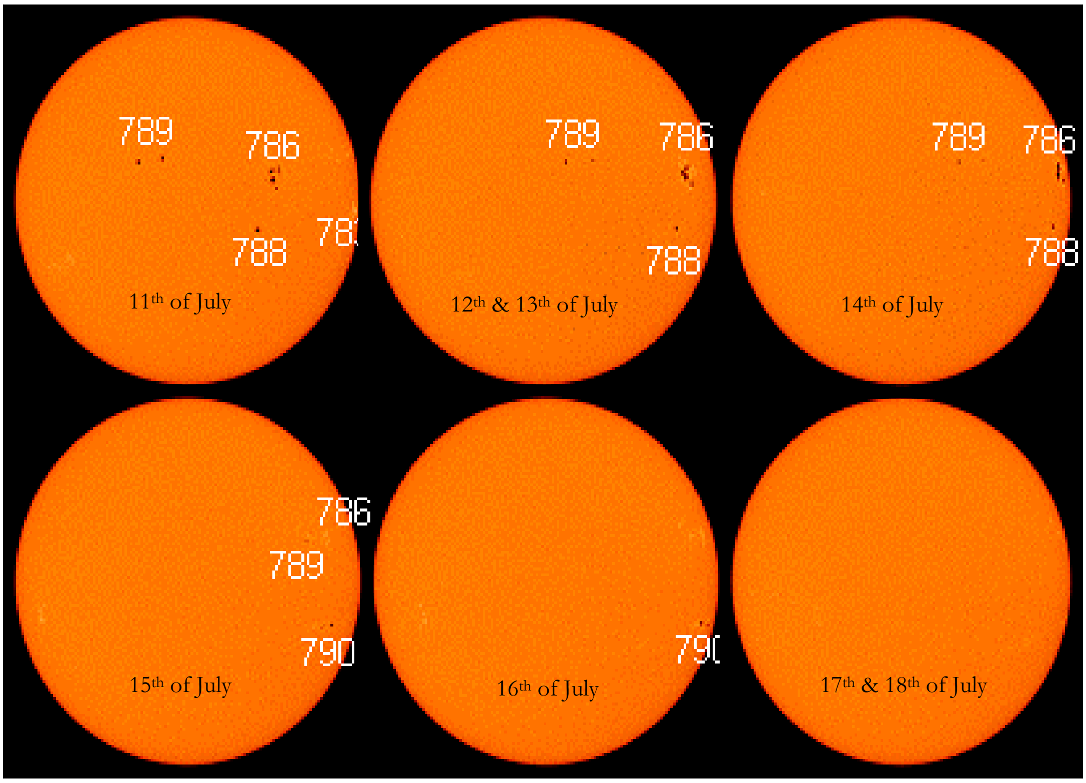

Figure 1: The development of Sunspots from July 11 to July 18

field was impacted by the weak shock arrived at Earth on the 17 July at 1:23 UT (see Figure 2).The same active region (AR) was also responsible for a long duration C2.3 flare which occurred on the 15 July from 09:43 UT to 17:15 UT. This event was associated with a partial halo CME observed on LASCO imagery. A summary list of all solar flares occurred from the 11 to 17 July is given in *Table I*.

Finally a back-sided full halo CME was observed by LASCO on the 17 July at 11:30 UT in the AR10786. This region started its activity after the 10 July, but it worked most intensively nearly and behind the limb. Especially interesting situation was observed on the 18 July, when the visible part of the solar disk was absolutely spotless, but on the back side, region 786 continued to be very active and produced several backside full halo CMEs.

At this point it is important to notice that besides the AR 786 there was another region of interest – AR10790 (S10, L=013) which appeared on the 13 July at the face of Sun, showed a steady growth in sunspot and magnetic complexity. It was the source of an M1.0 flare, occurred on the 16 July at 03:38 UT, and a long duration C7.3 flare that occurred at 15 July at 20:10 UT until the 16 July at 00:05 UT. The remainder of the disk and limb was quiet and stable. On the 18 July although the Sun was spotless in the Earth side, it had a good sized sunspot in the far side. This sunspot traced from the 14 July and had a significant role to solar activity that has been recorded during the past few days. The choice of the 18 July for the revealing of the far side sunspot was made on the base of visual contradiction. On the one hand the spotless Earth side Sun and on the other hand the back sided sunspot. Holographic images of the Sunspot evolution in the Earth side and the far side of the Sun are presented in Figure 3.

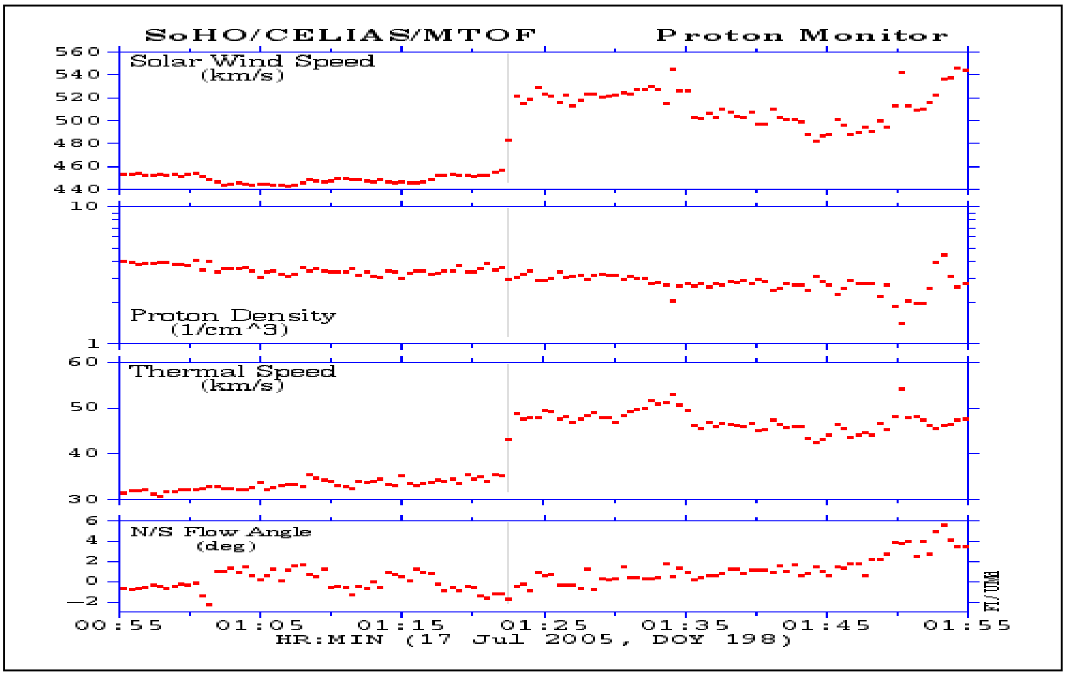

Figure 2: Evidence of the shock arrival (very weak) on 17.07 at ~1:23 UT whereas FD started on 16.07 around 15 UT

All data used in this study are taken from the web site http://sec.ts.astro.it/sec_ui.php, especially Solar Flare data from http://www.ngdc.noaa.gov and CMEs data from http://lasco-www.nrl.navy.mil

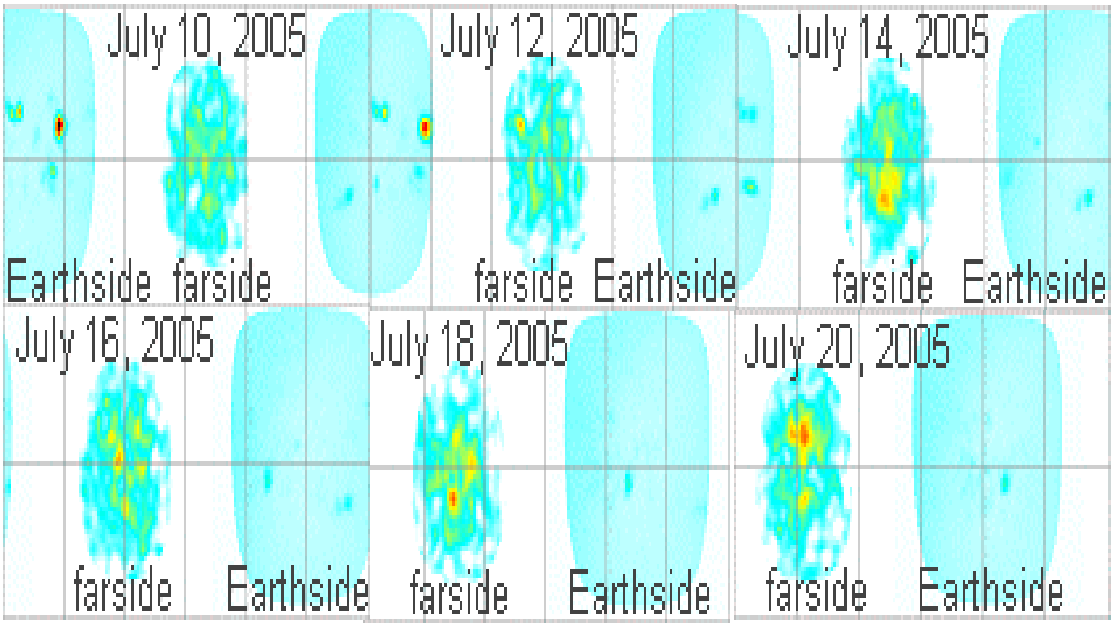

Figure 3: Holographic images of the Earth side and the far side of the Sun

Days of July	Number of solar flares in C class	Number of solar flares in M class	Number of solar flares in X class
2005 July 11	4	0	0
2005 July12	11	3	0
2005 July 13	6	5	0
2005 July 14	3	4	1
2005 July 15	6	0	0
2005 July 16	4	1	0
2005 July 17	1	0	0

Table I: A summary of all solar flares from 11th to 17th of July, 2005

3. Interplanetary and Geomagnetic activity

On the 12 July a discontinuity on the solar wind parameters indicated the arrival of a shock. Indeed a major storm took place (Kp=6), related to a halo CME occurred on the 9 July (M2.8 from NOAA region 786). Solar wind speed gradually increased up to 550 km/s throughout the 12 July. The IMF Bz fluctuated from +10 to – 15 nT during about 10 hours. Thereafter IMF remained north, near +5 nT.

Early on the 13th of July a change in the parameters of solar wind indicated the arrival of a new CME activity that took place on the 10 July (C1.6 from NOAA 783). The solar wind speed exceeded 600 km/s, and then it gradually decreased to 400 km/s on 16 July. Kp index remained at low level (Kp = 3). The IMF did not vary significantly beyond + / - 5 nT. A little higher geomagnetic activity (Dst index fall down to ~70 nT) was observed around 16-17 of July, which was most likely related to CME activity from 14th of July.

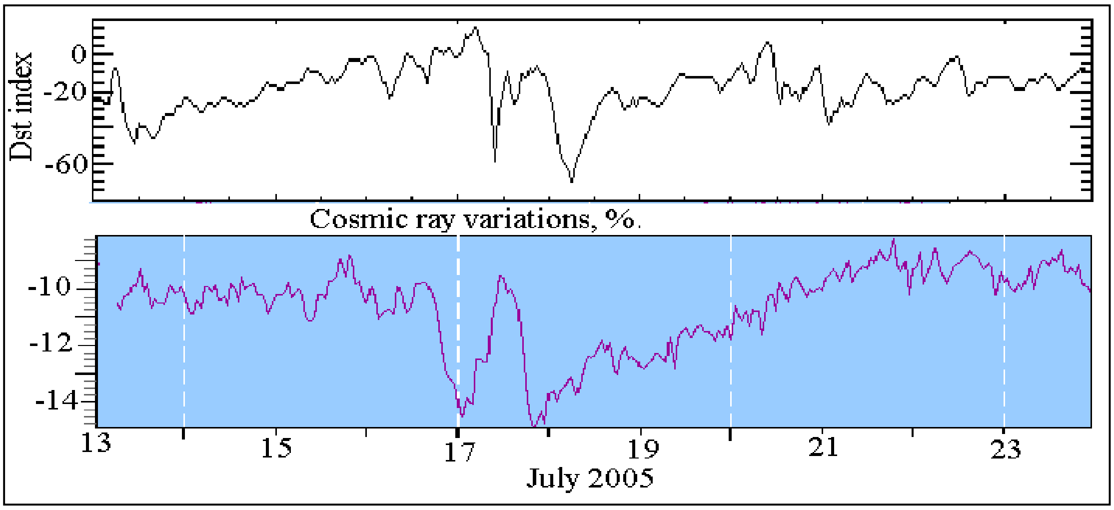

Figure 4: Dst variations and cosmic ray counting rate in the Athens NM.

Finally on the 17 July a weak signature of the interplanetary shock were detected at ACE which most likely was from X1.2 flare and the CME that followed it that took place on the 14 July, as can be seen in Figure 3. As a result solar wind speed increased until 525 km/s for about 6 hours and decayed to 450 km/s by the end of discussed period. The IMF Bz component fluctuated between +/- 10 nT for about 15 hours and ended the period southward to – 10 nT. This caused a period of major storm conditions on the 17 and 18 July (Kp = 5 / 6). By the end of this period, geomagnetic conditions were unsettled to active at all latitudes which are also confirmed by Dst index values appearing in the upper panel of Figure 4.

4. Cosmic ray activity

Heightened solar activity in the second decade of July 2005, especially in the western part of the solar disk, created disturbed situation in the interplanetary space that reflected in CR behavior. Density of the galactic CR started to fall down from 10 July and had a decrease ~2% by the 16 July after a series of relatively weak Forbush effects. Most dramatic events occurred on 17.07 when FD reached 8% in several stations just in a few hours. The CR intensity recovered rapidly up to the start level, but in the mid of 17.07 a sharp decrease started again and reached the same 8% at many stations with the following classical FE profile. These unusual cosmic ray variations recorded by Neutron Monitors (NM) at Alma-Ata, Apatity, Athens, Jungfraujoch, Kiel and Tibet stations are presented in Figure 5. The sharp increase during the 17 July reached the level before the onset of the Forbush decrease in all stations.

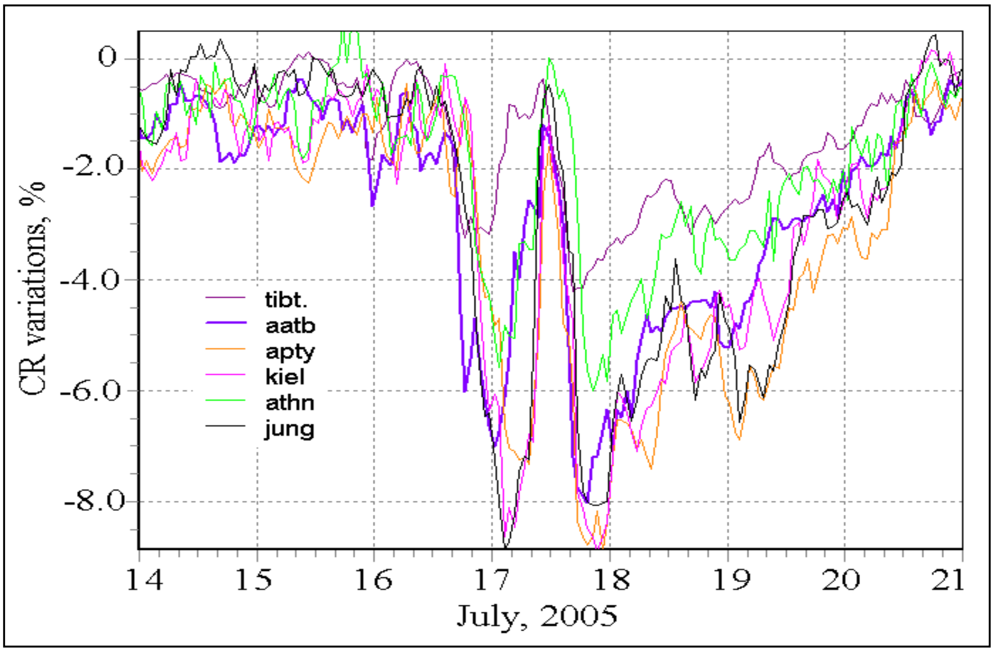

Figure 5: Unusual cosmic ray variations recorded by Neutron Monitors at different stations: Aatb- Alma-Ata, Apty- Apatity, Athn- Athens, Jung- Jungfraujoch, Kiel- Kiel, Tibt- Tibet

A verification of the unusual CR behavior on July 2005 has also been made by the Athens Neutron Monitor Data Processing (ANMODAP) Center *(Mavromichalaki et al, 2005a; b)*. On the 16 July the ANMODAP Center recorded a Forbush decrease from 23 neutron monitors in real time around the globe (6% variation in Athens). The decrease had a significant signature in almost all stations despite their geographical position. Neutron monitor data from all real time stations (left panel) and satellite data from GOES and ACE (right panel) for the time interval 12 - 21 of July 2005 are presented in Figure 6 *(Mavromichalaki et al., 2005a)*

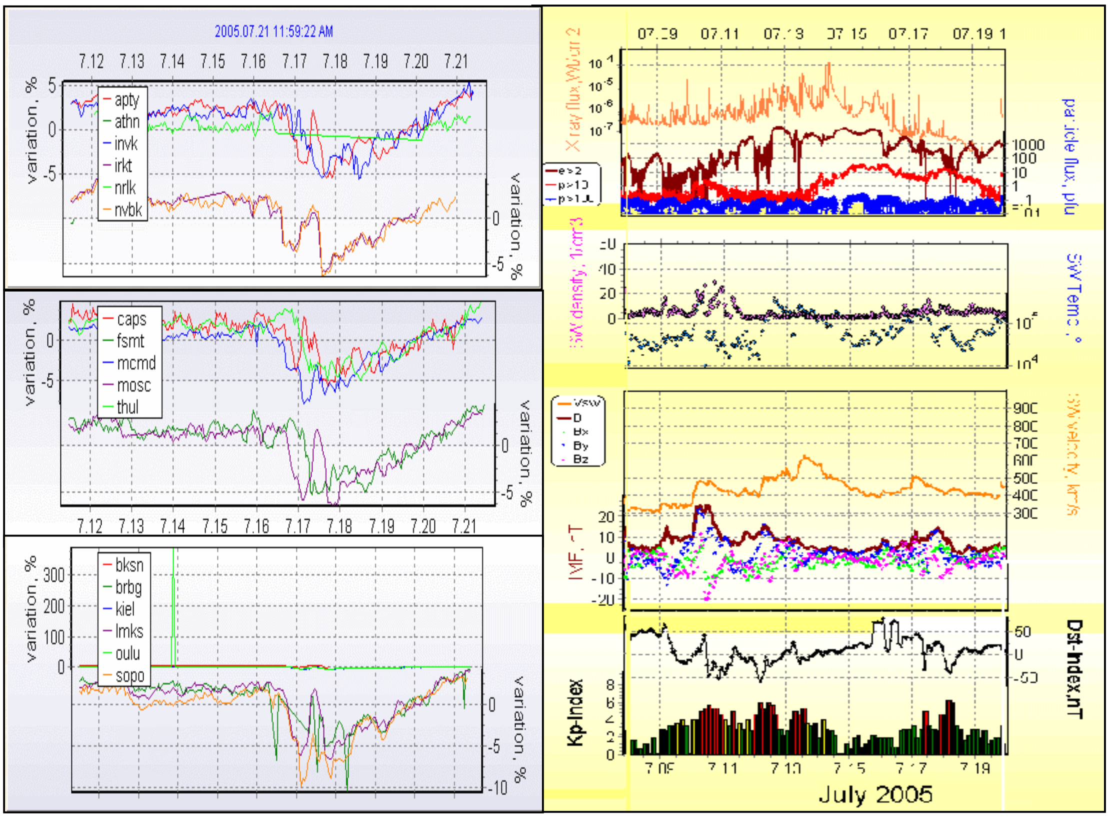

Figure 6: NM Data from ANMODAP center (left panel) and satellite data from GOES and ACE (right panel) for the period 12 – 21 July 2005 (http://cosray.phys.uoa.gr)

NM stations	**Event started at**	**Established alert signal**	**Maximum of the event**
MOSCOW	9:52 UT	9:57 UT	10:48 UT
KIEL	10:13 UT	10:17 UT	10:48 UT
OULU	9:59 UT	10:03 UT	10:47 UT

Table II *: The outcome of ANMODAP's Onset*

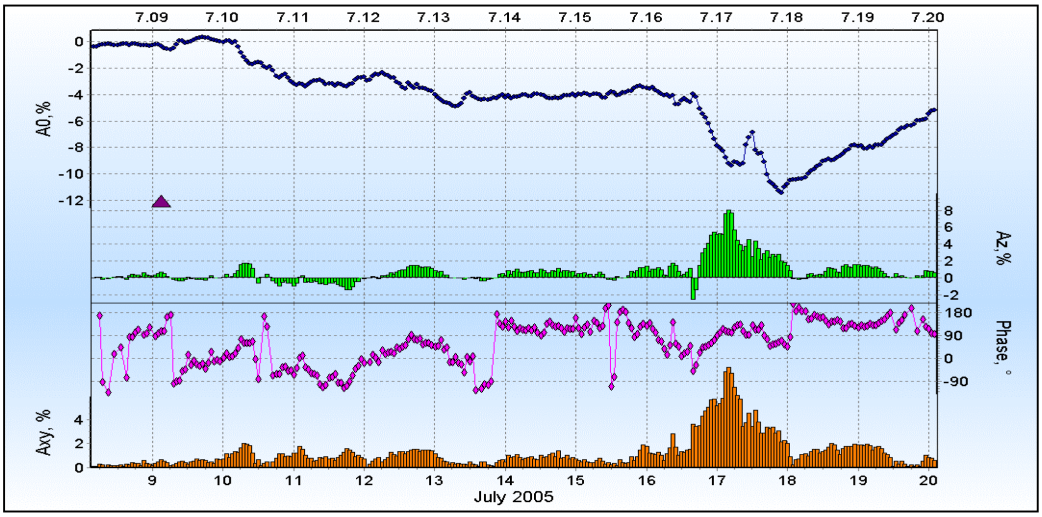

Figure 7: The behavior of CR density AO (solid line), North-South (Az) and ecliptic components (Axy) of CR anisotropy derived by GSM method from the data of world wide NM network.

In Figures 7 and 8 the behavior of the CR density and the first harmonic of anisotropy are presented by different ways: graphs and vectors *(Belov et al, 2005).* The calculation of the Ax, Ay and Az components of anisotropy is being performed by the Global Survey Method (GSM) using data from as many as possible (40-45) neutron monitors with their own properties (coupling coefficients and yield functions). All three components reveal sharp and big changes that occurred on the background of a more or less quiescent interplanetary and geomagnetic conditions (*Chen et al., 1993; Hofer et al., 2000*).

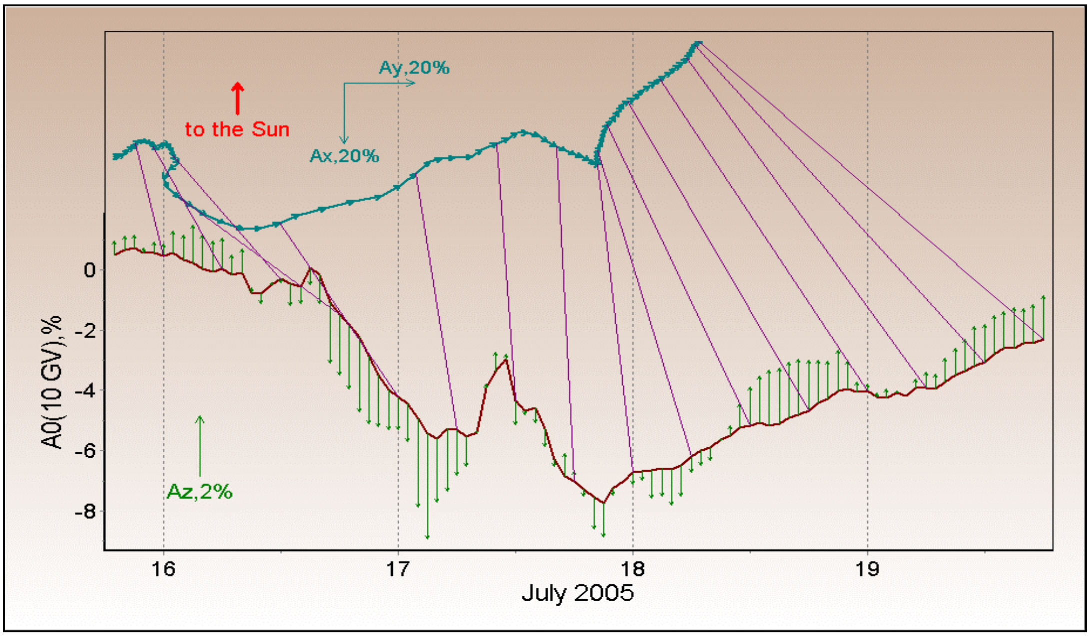

Figure 8: CR density AO and anisotropy. The vector diagram presents the anisotropy equatorial component, while vertical vectors, on density curve present the anisotropy north-south component during the Forbush effect on 16-17 July 2005. Thin lines connect the same times from the vector diagram and density curve.

The Onset program of ANMODAP Center can determine whether or not the enhancement which was recorded on the 17 July was a Ground Level one (GLE) or a geomagnetic disturbance (*Mariatos et al, 2005*). The outcome of the Onset process showed that it was nor a GLE or a geomagnetic disturbance (*Table II*). The Onset program uses hourly cosmic ray data and although there was an enhancement it was more gradual and without increase in the X-ray or particle channels from GOES. The geomagnetic activity remained in low levels. As a result, the enhancement did not present typical characteristics of a GLE or geomagnetic effect. Parameters in the interplanetary space and characteristics of the 10 GV cosmic rays derived from Neutron Monitor Network (NMN) throughout the period 9-19 July 2005 were used to estimate the situation in the inner heliosphere.

5. Discussion

Large Forbush decrease (~8%) and sharp changes of the anisotropy occurred on the background of more or less quiescent interplanetary and geomagnetic conditions on 16-17 July 2005,appears to be a consequence of the limb and backside solar activity that time. Forbush decrease started on 16 July was followed by a sharp enhancement of cosmic ray intensity to be continued by a second decrease with the following classical FE profile. A disturbance in near Earth space at this time (V=500 km/s, H~ 10 nT, Bz component was nearly -10 nT) could not provide such a magnitude of the FE. Usually under such modest parameters Forbush decrease hardly reaches ~2% (*Belov et al., 2001*)

As it is known, power X-ray western (limb) flares on 14.07 (M9.1 and X1.2) in the AR 10786 were followed by CMEs with full asymmetric halo, and CME from X1.2 flare is profoundly affected by the CME event associated to the M9.1 X-ray event. The mean speed of these events became 1430 km/s and at the initial moment it was ~2280 km/s. It is not improbable that such a disturbance caused gigantic Forbush effect in the western part of the inner heliosphere, and Earth crossed its periphery area on the beginning of 17.07. This day a “weak” shock was recorded at 1:32 UT, but Forbush decrease at Earth started before this shock arrival and at different time in different longitudes that is a consequence of the complicated conditions for CR propagation. A big equatorial component of CR anisotropy at this time is evidence of an intensive inflow of particle flux from the eastern direction that provided fast recovery of the FD. But LASCO/EIT observed also this day an asymmetric Full Halo Event started at 11:30 UT as a very strong brightening above the NW limb associated to the behind of limb flare in the same AR10786. By 11:54 UT, faint loop-like extensions can be seen all above South Pole. The velocity of this “backside” event was 1300 km/s. Directly from this moment the new sharp decrease of CR intensity started on the background of very high anisotropy, and this time coincidence seems not to be occasionally but caused by changing of the conditions for particle propagation.

Moreover the decrease of CR intensity was probably influenced by the weak shock that reached the Earth at 1:23 UT on the 16th of July 2005, approximately six hours after the beginning of the decrease. Furthermore the sudden increase of CR within 17th of July could be the result of solar activity that had been recorded earlier and reached the Earth at this time. It is a possible explanation because of the fact that during the previous days four CMEs took place, two bright and fast halo CMEs on the 14th and two partial halo CMEs on the 15th and 16th of the month, respectively. Specifically the first of the halo CMEs that took place on the 14th of July 2005 might be the cause of the giant FD, westward the Earth, as its periphery crossed Earth on the 16th of this month.

In any case, a first reading of all available data implies interesting events that could be the outcome of solar activity of the far side of the Sun generated by special interplanetary conditions. A more detailed analysis will be followed in order to provide physical answers to this certain peculiarity of cosmic ray behavior with possible great scientific content.

Conclusions

From the above analysis based on all available neutron monitor and satellite data can be concluded that:

- The intense solar activity that forehanded the extreme cosmic ray events on the 16 and the 17 July could provide the Forbush effect of the 16 July, although not with such a great amplitude (8% in all neutron monitor stations).

- The big equatorial component of CR anisotropy observed at the same time is evidence of an east-opened structure caused an intensive inflow of particle flux from the eastern direction that provided fast recovery of the FD just after the minimum.

- The geomagnetic and interplanetary conditions near Earth were relatively quiescent, and geomagnetic field was disturbed essentially less than cosmic rays, although the minor magnetic storm evolved on the 17 July after the weak shock arrival, when Kp index exceeded the value 5.

- The sudden CR increase on the 17 July did not present the characteristics of a ground level enhancement or a geomagnetic effect confirmed by the onset program of ANMODAP center determined. In a whole the CR behavior on 16-17 July is the result of the crossing by Earth a complicated structure of the periphery area of the giant Forbush effect that developed in the western part of the inner heliosphere after the full halo CME released on 14 July, 2005.

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