Cosmic ray modulation in August-September 2005

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Abstract

During the burst of solar activity in August-September 2005, close to the minimum of the current solar cycle, a big amount of powerful X-ray flares was recorded. Among them a solar flare X17.0 on 7th of September was outstanding. Within a relatively short period (22 August – 17 September) two severe magnetic storms were recorded as well as several Forbush effects, which has been studied in this report using the hourly mean variations of the cosmic ray density and anisotropy derived from the data of the neutron monitor network. The behavior of certain characteristics of the high energy cosmic rays during these Forbush effects is being analyzed together with interplanetary disturbances and their solar sources in comparison with the variations of the geomagnetic activity. A big and long enough cosmic ray pre-decrease is selected before the shock arrival on 15th of September, 2005.

Solar Activity

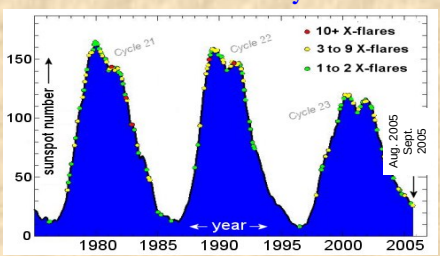

Figure 1:Sunspot number as index of solar activity during the last three solar cycles; Credit: David Hathaway, NASA/MSFC

- The period under consideration is a very intense one, as a number of strong solar events were recorded. September 2005 which is at the end of the current solar cycle appears to be much more energetic compared to March 1991 which was at the maximum of the previous solar cycle.

- At the 22nd of August an M5.6 flare was recorded, originated from AR 798.

- September was a highly energetic month as a total of 90 C-class, 32 M-class and 11 X-class flares were recorded. This period was distinguished by an X17 solar flare which was the 5th on rank at the SOHO's 'monster flares' catalogue.

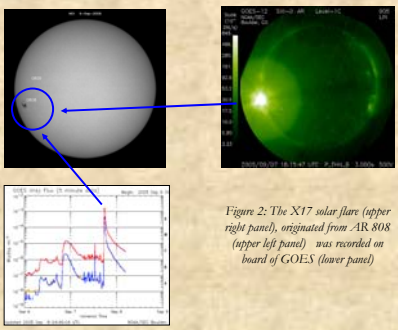

Figure 2: The X17 solar flare (upper right panel), originated from AR 808 (upper left panel) was recorded on board of GOES (lower panel)

Cosmic Ray Modulation

- Data on the solar wind velocity and IMF intensity as well as data of cosmic ray density and the ecliptic component of anisotropy together with data of the geomagnetic activity are presented for the period 20 August-29 September 2005 in Figure 3. As one can see from the behavior of all these parameters, each episode of solar activity has resulted well pronounced disturbance in the interplanetary space. Many shocks were produced, which sometimes, despite a remote source location, reached at the Earth and caused strong geomagnetic storms. Each disturbance modulated galactic cosmic rays creating series of significant Forbush effects (FE). The main parameters, characterizing the situation on the Sun, in the interplanetary space, in the geomagnetic field and in the galactic cosmic rays during the period under consideration are introduced in Table I.

August 2005

- On the 22nd of August a series of perturbations in the near Earth space, was evolved because of the M5.6 solar flare. This resulted into a Forbush decrease on the 24th of the month. Later on, two other shocks arrived at the Earth and created two moderate magnetic storms (Kp~5-6) and two small Forbush decreases (~ 2-2.5%) on 31st of August and 2nd of September

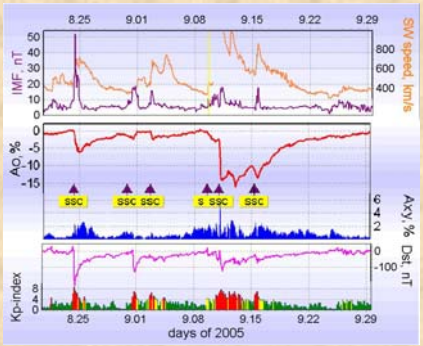

Figure 3: Parameters of the solar wind (upper panel), density (A0) and anisotropy (Axy) of the CR (mid panel), and Dst and Kp indices of geomagnetic activity as well (lower panel) in August-September 2005. SSC – correspond to the moment of shock arrival at the Earth.

Interplanetary disturbances				Associated flares					FE		Kp	Dst
Date	Time (UT)	Vin (km/s)	VH	Date	Time (UT)	Lat. (°)	Long. (°)	Import	A0 (%)	Axy (%)		(nT)
24.08	4:43	1113	18.7	22.08	16:46	13°S	65°W	M5.6	6.4	2.61	8.67	-216
09.09	14:01	931	3.21	07.09	17:17	11°S	77°E	X17.0	3.2	2.37	5.67	-60
11.09	01:14	1328	8.89	09.09	19:13	12°S	67°E	X6.2	12.1	5.84	7.67	-123
12.09	06:00	1282	4.77	10.09	21:30	13°S	47°E	X2.1	5.1	2.87	7	-94
15.09	09:04	1118	1.53	13.09	19:19	10°S	09°W	X1.5	4.2	1.52	3.33	-38

Table I: Vm – mean velocity of the disturbance propagation from Sun to Earth; VH- product of the maximum SW velocity and IMF intensity in the fixed time near Earth; A0- the CR density variation, Axy- equatorial component of the CR anisotropy derived by GSM method from neutron monitor network; Kp u Dst – indices of geomagnetic activity.

Cosmic Ray Anisotropy

September 2005

- The first effect in September's events series is associated with the shock arrival on 09.09, after the flare X17.0 occurred on 7th of September at 77°E longitude. The jump of the SW velocity and IMF intensity was very small. The amplitude of the FE was only 3.2% and the geomagnetic activity was very weak.

- The next disturbance on 11.09 associated with the flare X6.2 at longitude 66°E, created a strong geomagnetic storm and caused a large FE with a fast decrease of the CR intensity down to ~12% and a high anisotropy of GCR (up to 5.8% in the ecliptic component of the 10 GV particles). The ejecta propagated with a velocity of 1328 km/s, the SW speed was increased up to 980 km/s and the intensity of the IMF was up to 20 nT !

- Both these eastern solar flares (X17 and X6.2) were followed by significant proton fluxes. The proton flux for particles >10MeV has increased up to 1000 pfu. Rosetta /SREM, located 30° behind the Earth at a distance ~1.3 AU, registered a proton flux which was ~ 100 000 pfu. Such great proton fluxes from the eastern flares (even if taking into account all flares with longitudes >45°E) had never before been observed.

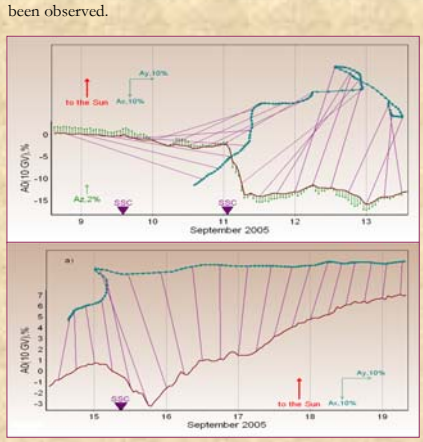

Figure 4: Behavior of the CR density (A0) and ecliptic component of the CR anisotropy (Ax-Ay) with rigidity 10 GV during 9-13(upper panel) & 14 - 20 (lower panel) September 2005. Vertical vectors represent the north-south component of the anisotropy. Triangles mark timing of shock arriving.

- The last FE of this series is also related to a disturbance arrival on 15.09 after the flare X1.5 from eastern longitude, which did not produce strong changes in the parameters of interplanetary space and in the geomagnetic situation, but it led to a significant Forbush decrease (4.2%).

Pre-Decrease of Cosmic Rays on the 15th of September 2005

- The shock of 15th of September came a little bit later then the onset of a CR density decrease, so this case appears to be a good example of pre-decrease in the CR intensity.

- As one can see in Fig. 5 (upper panel), the distribution of the CR variations from different stations in 14-15 September is presented by the asymptotic longitudes as it was determined by the "ring stations" method. It is notable that about 3 UT on 15.09 the feature of the distribution is sharply changed: the narrow region of the longitudes (in a sector 90°-180°) with low CR intensity stands out against the background of the strong increase of the CR variations. This peculiarity becomes to be especially well pronounced from ~6 UT that is 3 hours prior the SSC.

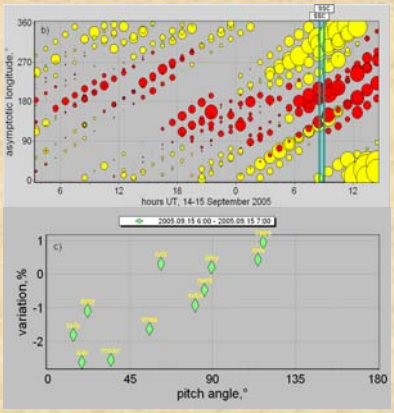

Figure 5: Distribution of the CR variations by the asymptotic longitudes after deduction of the isotropic part (red circles-decrease of intensity, yellow-increase relatively to the base value; the size of circle is proportional to the variation magnitude; vertical lines are the timing of the shocks (upper panel); pitch-angle distribution of the CR variations in two hours prior the SSC (lower panel)

- Usually, pitch angle anomalies in the CR distribution appear before severe magnetic storms. These anomalies are most often observed in the last hours before shock arrival, typically within four hours. The pitch-angle distribution for the 7-th hour on the 15th of September, almost two hours prior to the shock, is plotted in Fig. 5 (lower panel).

Conclusions

- Perturbation of the interplanetary space in August-September 2005 caused a series of modulation effects in CR, as a result of the solar flare activity close to the minimum of the current solar cycle.

- In the forming of this disturbed situation three eastern, one central and one western CMEs, associated with X-ray flares, took part.

- Modulated effect of disturbed regions on the galactic cosmic rays revealed in the series of Forbush effects three of which are distinguished by the magnitude of CR density decrease: 24-25 August (amplitude 6.4% for the CR with rigidity 10GV), 11 September (12.1%) and 15 September (5.1%). In all these cases very fast shocks arrived at the Earth with the mean velocity of propagation exceeded 1100km/s

- Western (22.08) and eastern (07 and 09.09) flares were very remote sources, but even in these cases significant effects in CR and in the Earth's magnetosphere were recorded.

- In 15th of September, a big and long lasted pre-decrease in the CR density preceded the shock arrival, which is clearly isolated also by the longitude and pitch-angle distribution of the CR intensity.

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