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Abstract. *Aims.* We analyze the kinematics of three interplanetary coronal mass ejections (ICMEs) that occurred on 13th, 14th and 15th February 2011 in the active region AR 11155 and have shown that they appeared at the Earth orbit on February, 18th and caused Forbush decrease (FD). *Methods.* The solar coordinates of flares are (S19W03), (S20W14) and (S21W18). The kinematic curves were obtained using STEREO (A&B) data. Additionally, we explore the possibility of the CME-CME interaction for these three events. We compare obtained estimates of ICME arrival with the in-situ measurements from WIND satellite at L1 point and with ground-based cosmic ray data obtained from SEVAN network. *Results.* The acceleration of each CME is highly correlated with the associated SXR flares energy release. CMEs that erupted at 13 and 14 Feb 2011 are not associated with prominence eruption; maximum velocity was v_{max}≈550 ± 50 km/s and v_{max}≈400 ± 50 km/s, respectively. However, 15 Feb 2011 CME is connected with much more violent eruption associated with a prominence, with maximum velocity of v_{max}≈ 1400 ± 50 km/s. The last overtakes 13th and 14th Feb CMEs at distances of 32 and 160 R⊙, respectively.

1. Introduction

Interplanetary coronal mass ejections (ICME) are the manifestations of coronal mass ejections (CME) observed by coronagraphs near the Sun. Their associated effects include the generation of upstream shocks which may accelerate energetic particles, Forbush decreases (FD) in the galactic cosmic ray intensity, and can lead to significant geomagnetic disturbances on Earth and may have negative impacts upon space-born instruments susceptible to high levels of radiation when outside the protection of Earth's magnetosphere [1].

SEVAN (Space Environmental Viewing and Analysis Network) is a network of particle detectors located at middle to low latitudes [2,3,4,5]. SEVAN modules were designed for the research of the modulation processes solar activity cause on the secondary cosmic rays and to study the cosmic ray variations due to electron acceleration in the thunderclouds. SEVAN measures fluxes of neutral and charged components of the secondary cosmic rays above ~10 MeV and high-energy muon flux (> 250 MeV). One of the major advantages of these multi-particle detectors is probing of different populations of the secondary cosmic rays, initiated by particle cascades in terrestrial atmosphere. With basic detector of the SEVAN network we simultaneously measure changing fluxes of the low energy charged particles (mostly electrons and muons, E < 100 MeV), high-energy muons (E >250MeV) and the neutral component of the secondary cosmic ray flux – neutrons and gamma rays. The first SEVAN modules are under test operation at Aragats Space Environmental Center in Armenia, in Bulgaria, in Croatia and in India (we use the data only from Aragats detector placed in Aragats Space Environmental Center; http://adei.crd.yerphi.am/adei/).

In this paper we study the response of the world-wide network of SEVAN modules on CR variations, namely we perform the analysis of FD, registered by SEVAN network on 18 February, 2011, in conjunction with space stations WIND and STEREO (A & B) to determine which of the CMEs, emitted on 13th, 14th and 15th February was the cause of the registered FD.

2. Observations and method

From 13 to 15 February there were observed three solar flares: M6.6 -13 Feb., M2.2 -14 Feb. and finally on 15 Feb. - X2.2-class, all three were released almost from the center of the solar disk (see Table 1 for solar coordinates), and accompanied by the CMEs emission. CMEs originating within 45° from the disk center propagate roughly along the Sun-Earth line, so the front-side halos are highly likely to arrive at Earth, therefore, we can conclude that all three CMEs emitted 13-15 February can unleash a magnetic storm and Forbush decrease. And in fact, the global network of neutron monitors registered a start of FD at 2:00 - 5:00 UT, February 18. WIND spacecraft registered sharp jump of the solar wind velocity at 0:42 UT. The solar wind speed during second jump much larger than during the first one, as a rule, assumes different ICME arrival at the point L1. The FD profile as measured by SEVAN Aragats detector also demonstrates two FD minimums anti-correlating with maximums of the solar wind speed (Fig. 1). First of all we have to determine the velocity of all three CMEs between the Sun and the Earth to estimate the time of their appearance at the Earth's orbit.

The analysis of the kinematics is focused on the distance-time measurements of the leading edge of the ICME. The identification of the feature was accomplished by comparing and matching their kinematical curves $h(t)$. After the corresponding features in EUVI, COR1, COR2 and HI-1 images were properly associated the data were joined for a given feature and smoothed. The smooth function uses a symmetric k nearest neighbor linear least squares fitting procedure (in which k is adaptively chosen) to make a series of line segments through our data. Speed was then determined using two successive smoothed data points: $v(t_{vi}) = (r(t_{i+1})-r(t_i))/(t_{i+1}-t_i)$, where $r(t_i)$ is the height at time t_i and $t_{vi} = (t_{i+1}+t_i)/2$. The obtained speed-time dependence is then again smoothed. In the following step, we have determined the acceleration applying: $a(t_{ai}) = (v(t_{vi+1})-v(t_{vi}))/(t_{vi+1}-t_{vi})$, where $v(t_{vi})$ is the height at time $t_{vi}$and $t_{ai} = (t_{vi+1}+t_{vi})/2$. See Table I, (the date and start time, the location of the ICME source region at the beginning of the eruption, the associated active region, the velocity peak, the velocity in the late phase of the eruption, the peak value of the acceleration, the deceleration in the late phase, and the duration of the acceleration phase). For the calculation of the arrival time we take that 18th Feb 2011, when ICMEs are detected by WIND satellite, Earth was at a distance of 212.36 solar radii. The calculated arrival times obtained using *STEREO A & B* data for analyzed ICMEs are presented in first two columns of Table II. From the obtained kinematical and flare energy release data, we derive the time differences between the beginning of the acceleration phase and the onset of the SXR burst, Δt_b, the difference between the peak acceleration and the peak of the SXR derivative, Δt_m, and the difference between the end of the acceleration phase and the end of the SXR burst growth (i.e., the SXR peak), Δt_e. The class of accompanied flares, the SXR burst rise time T_{SXR}, and time differences Δt_b, Δt_m and Δt_e are presented in last five columns of Table 1.

Table 1. Kinematical characteristics of analyzed ICMEs with characteristics of associated *SXR* bursts. In the last row standard deviations are given.

Date and start time (UT)	*location*	*active region*	v_m *km/s*	v_{lp} *km/s*	a_m ms^{-2}	a_{dec} ms^{-2}	T_{acc} *min*	*SXR class*	T_{SXR} *min*	Δt_b *min*	Δt_m *min*	Δt_e *min*
13 Feb 2011 17:24	S19W03	*11155*	*550*	*410*	*370*	*0*	*42*	*M6.6*	*10*	*16*	*-1*	*-14*
14 Feb 2011 17:06	S20W14	*11155*	*400*	*400 after distance >32 solar radii 560*	*95*	*0*	*132*	*M2.2*	*7*	*31*	*-19*	*-48*
15 Feb 2011 1:50	S21W18	*11155*	*1390*	*560*	*2560*	*-5*	*23*	*X2.2*	*12*	*2*	*2*	*-5*
		stdev	*10*	*10*	*10*	*5*	*5*		*1*	*2*	*1*	*2*

For the identification of the FD event we use the pressure corrected data from SEVAN. Estimated onset and minimums of the FD are presented in last three rows of Table 2, respectively.

Table 2. Computed arrival times of the analyzed ICMEs, with onset of the increase in different SW parameters and FD. In the last column standard deviations are given.

ICME - date and start time (UT)	*13 Feb 2011 17:24*	*14 Feb 2011 17:06*	*15 Feb 2011 1:50*	*Stdev (hours)*
estimated arrival time from STEREO A data	*14:10 UT 18 February 2011*	*07:10 UT 18 February 2011*	*01:05 UT 18 February 2011*	*± 2*
estimated arrival time from STEREO B data	*13:20 UT 18 February 2011*	*07:30 UT 18 February 2011*	*02:20 UT 18 February 2011*	*± 2*
onset of increase for B(total)		*00:42 UT 18 February 2011*		*± 0.1*
onset of increase for B_z		*00:42 UT 18 February 2011*		*± 0.1*
onset of increase for N_p		*00:42 UT 18 February 2011*		*± 0.1*
onset of increase for v		*00:42 UT 18 February 2011*		*± 0.1*
onset of FD		*02:30 UT 18 February 2011*		*± 0.5*
first minimum of the FD		*06:50 UT 18 February 2011*		*± 0.5*
Second minimum of the FD		*12:22 UT 18 February 2011*		*± 0.5*

3. Results

13th Feb CME was first seen in the EUVI *STEREO B* image at 17:23:34UT; 13 Feb 2011, at a heliocentric distance of R = 1.3 R⊙, while 14th Feb CME was first seen in the COR1 *STEREO B* image at 16:15:51UT; 14 Feb 2011, at a heliocentric distance of R = 1.5 R⊙. CMEs attained the maximum velocity of $v_m \approx 550 \pm 10$km/s and 400 ± 10km/s, respectively. Their main acceleration phase reached maximum at approximately 17:40UT 13th Feb and 17:20UT 14th Feb, respectively and lasted for some 40 minutes and 2.2 hours, respectively. The 13th Feb CME reached the maximum acceleration of $a_m \approx 370 \pm 10$ ms^{-2} at the heliocentric distance of R=1.4 R⊙, while 14th Feb CME reached the maximum acceleration of a_m≈95 ± 10 ms^{-2}at R = 2.4 R⊙. For both events the acceleration took place below the radial distance of R = 5 R⊙. In the late phase of the eruption, the velocity of 13th Feb CME becomes roughly constant at the value of around 500 km/s. 14th Feb CME reaches a roughly constant velocity of 400 km/s in the late phase of the eruption, but after the heliocentric distance of R = 32 R⊙, velocity suddenly increases to ≈ 800 km/s. 15th Feb CME reached a relatively high maximum velocity of v_{max}≈1390 ± 10km/s at the height of 2 solar radii. This is significantly faster than the ambient solar wind. The acceleration phase took place below 2 solar radii, the maximum acceleration of a_m≈2560 ± 10 ms^{-2} was reachedat the heliocentric distance of R = 1.1 R⊙. Kinematical curves indicate that the CME is gradually slowing down (decelerating) beyond 5 solar radii. We estimate that the deceleration in the late phase of the eruption is approximately *dec*≈-5 ± 10 ms^{-2}. 15th Feb CME arrives first at the Earth distance, therefore we expect it to interact with two CMEs that erupted earlier. Furthermore, from the estimated velocity in the late phase of the eruptions, it follows that joined structure of 14th Feb and 15th Feb CMEs reached the 13th Feb CME at the heliocentric distance of around R = 160 R⊙.

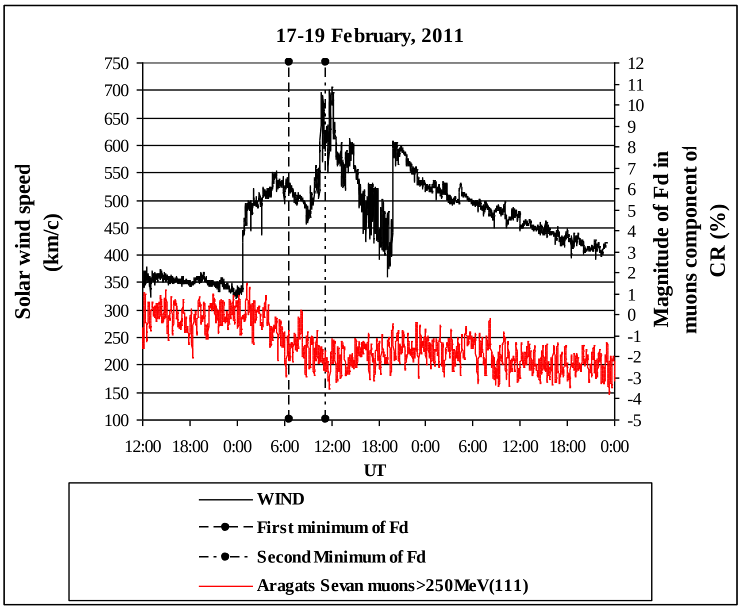

Figure 1. SEVAN (red) and WIND (black) data from February 17 to February 19, 2011

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