GROUND LEVEL ENHANCEMENTS AND THE RELATED SOLAR ACTIVITY DURING SOLAR CYCLE 23

Athens Neutron Monitor Station

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Abstract

Solar cycle 23 seems to be of great interest for the researchers due to many peculiarities. Having a relatively small sunspot number, an unusual distribution of the extreme solar events and especially of the ground level enhancements of the cosmic ray intensity, an unusual duration etc., it was rather different from the previous ones. A study of the parameters of the sixteen ground level enhancements recorded during the approximately 12-year period of it (1996-2008) together with the associated solar activity, including the main properties of the solar flares, the coronal mass ejections and the radio bursts, has been realised. All studied cases seem to be connected with very intense flares of long duration, having a mean importance value of X3.8 and a mean duration of 164.5 min, with either halo or partial halo coronal mass ejections with a mean linear velocity of 1876 km/sec as well as with intense radio bursts. It is also noticed that the ground level enhancements of the 23rd solar cycle occurred after the onset time of the associated solar X-ray flares with a mean time delay of about 38 min, very useful result for their monitoring and prediction.

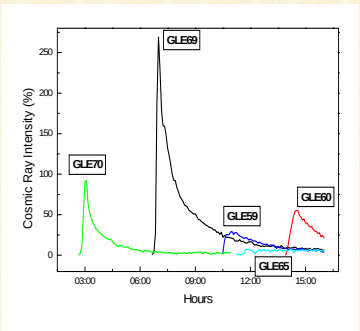

Fig. 1 The most intense GLEs of solar cycle 23, as were recorded from Oulu neutron monitor station

Ground Level Enhancements of Solar Cosmic Rays

Ground level enhancements of Solar Cosmic Rays (GLEs) are sharp increases of short duration in the counting rates of cosmic ray intensity. High energy particles (>500 MeV) penetrate along the geomagnetic field and enter the Earth's atmosphere.
During the 23rd solar cycle 16 GLEs of various intensities (ranging from 4% - 5442%) were recorded by the ground based neutron monitors, covering a 9-year period and having an unusual distribution in comparison to previous solar cycles, 4 in the inclining phase, 5 near the maximum phase and 7 GLEs in the extended declining phase.
Their list is given in Table I and the time profiles of the most intense events as recorded from Oulu are shown in Fig.1., with GLE60, GLE69 and GLE70 being very sharp while GLE59 and GLE65 featuring a wider profile. Some of the most intense events were recorded in the declining phase, including the great event of January 20, 2005, the % intensity of which reached >5000% in South Pole station, and it was detected even from mid-lat stations (Andriopoulou et al., 2009)
GLE parameters such as the onset time, the maximum % cosmic ray intensity and the time reached were determined as well as the main characteristics of their related solar phenomena and a comparison of their relative time differences was made in an effort to investigate their relation.

Table I. GLE events in solar cycle 23

# GLE	Date
GLE55	6 November 1997
GLE56	2 May 1998
GLE57	6 May 1998
GLE58	24 August 1998
GLE59	14 July 2000
GLE60	15 April 2001
GLE61	18 April 2001
GLE62	4 November 2001
GLE63	26 December 2001
GLE64	24 August 2002
GLE65	28 October 2003
GLE66	29 October 2003
GLE67	2 November 2003
GLE68	17 January2005
GLE69	20 January 2005
GLE70	13 December 2006

Solar activity

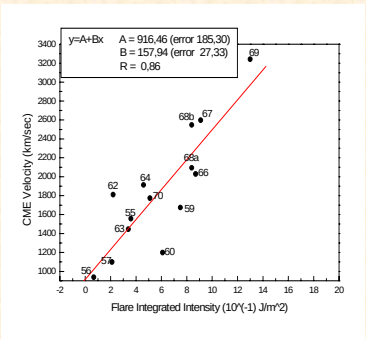

Fig. 2 Linear relationship of the flare integrated intensity with the CME velocity connected with the same event

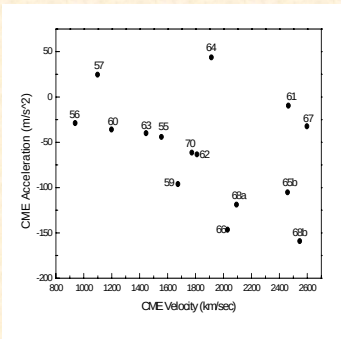

Fig. 3 Relation of the linear velocity with the acceleration of the CMEs

- All recorded cases seem to be connected with intense solar activity; a strong solar flare, a halo or partial halo CME, multiple radio bursts of type III, II and IV and an interplanetary shock that followed.
- All GLE-related flares are very intense (apart the flare of GLE61 which was behind the limb) and 87% of them had a west origination (Fig.4). Their mean importance value was X3.8, much greater to the mean value of the whole cycle, C1.6 (Gopalswamy et al. 2008) and their mean duration was 164.5 min.
- Each GLE was related to one CME except GLE65 and GLE68 that seem to be connected with a double CME and a double type II radio burst. Their linear velocities ranged from 938-3242 km/sec.
- In all studied cases except GLE65 the integrated intensity of the flares are in linear relationship with CME linear velocity (R= 0.86)(Fig2).
- In most cases as the linear velocity of the CMEs is higher the deceleration is more intense (Fig.3) (Andrews, 2003)

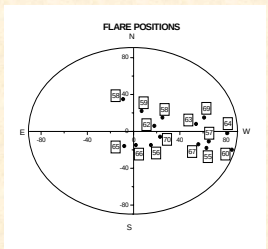

Fig. 4 Flare positions on the solar disk of the GLE-related flares

Flare-CME time relation to GLE events

Considering the flare onset time as the time reference and CME-onset time error of ±20 min and excluding GLE61 (flare behind the limb) and GLE58 (CME data gap) and using the GLE, CME and radio bursts onset times (Fig.5, Fig.6) it is derived that

- In 9/14 cases flares & CMEs were recorded simultaneously, in 2/14 the CME started earlier than the flare (one of them was the great event GLE69) and in 3/14 cases the flare started earlier.
- GLEs were recorded in the ground at least 11 minutes after the flare onset usually, with 37.8 min mean time and usually after the flare maximum time.
- All CMEs and almost all type II radio bursts occur in the inclining phase of the flare.
- In all cases at least one radio burst of each type II, III, IV appeared, usually near the maximum phase of the flare.

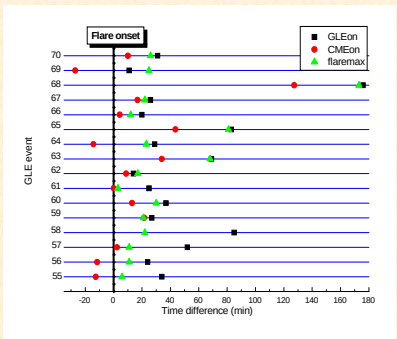

Fig. 5 Time relation of solar flares, CMEs and GLEs

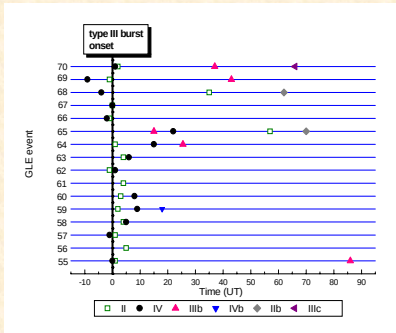

Fig. 6 Time relation of radio bursts

Conclusions

- **GLEs had an unusual distribution during the solar cycle 23, with the majority of the events occurring in the declining phase.**
- **All the GLE events were related to intense solar activity, strong solar flares, fast CMEs and multiple radio bursts.**
- **The related flares were very intense (X3.8), had a relative long duration (165 min), and covered large areas (450 arcsec^2).**
- **CMEs related to GLEs were halo/partial halo, fast (1876 km/sec) events, usually decelerating. There seems to exist an analogy between the CME linear velocity and the deceleration increase, also observed from Andrews (2003).**
- **In the majority of cases the solar flare and CME started simultaneously, providing evidence that they may be manifestations of the same phenomenon. The integrated intensity of the flare has also a linear relationship with the linear CME velocity.**
- **GLEs occur approximately 38 min after the onset time of the flare and usually after the flare maximum time.**

References

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