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Proton events at geostationary altitude during 2005, their relationship to solar wind and IMF parameters, and their 'geoeffectiveness'

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Abstract. Solar wind and IMF parameters from the ACE satellite at the Earth's dayside Lagrangian point LI, are examined during solar proton events of 2005 for 'shock' structures. The GOES-10 satellite at geostationary orbit (G) sees proton events in the 10-30 MeV energy range only when the flux of these particles exceeds (5×10^{-1}) protons/cm^2.sec.sr. (also known as pfu). Such events are invariably followed at G by REE (Relativistic Electron Events) which commence with an RED (Relative Electron Dropout). During REE, the enhanced flux of > 2 MeV electrons can exceed $(> 5 \times 10^4)$ pfu, and can cause operational anomalies on geostationary satellite instruments. Such large proton events also trigger off at Earth (E), ssc type of storms with typical signatures in the geomagnetic indices Dst and Kp, and large Forbush decreases in the Cosmic Ray Neutron Monitor (CRNM) Count. Relationships between the various Space Weather parameters recorded at L1, G and E during Proton events, assume special importance from the point of view of Satellite Anomaly predictions.

Keywords : Sun : activity, particle emission, solar-terrestrial relations

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1. Introduction

The Sun's influence on life on earth has been known since at least 5 millenia (the Indian Rigvedas, Chinese, Egyptian, Mexican and Peruvian texts). The Sun as a source of electromagnetic disturbance in the vicinity of Earth has been recognized since the work of Birkeland (1896), and Chapman & Ferraro (1931). The simple ground-based Cosmic Ray Neutron Monitor was one of the earliest instruments to suggest emission of MeV particles during solar flares (Forbush 1946). The Sun as a continuous emitter of low-energy Solar wind particles and Interplanetary Magnetic field was postulated by Alfv̈en (1950), Biermann (1951), and Parker (1958). The 'Geoeffectiveness'of solar disturbance has been examined by many researchers, amongst them being Ness & Wilcox 1965; Burlaga & Ness 1968. Recent works on this aspect include Gopalswamy 2005; Simnett 2006; Friedel et.al. 2002. More recently, it has been realized that solar emissions of all energy ranges can adversely affect life on earth, and semi-conductor devices aboard Geostationary Satellites (Miroshnichenko 2003; Rosen 1976; Paulikas & Blake 1976; Baker et. al. 1987). While the keV particles cause surface charging effects, those in the <10 MeV range cause deep dielectric discharges, and those with energy >10 MeV cause sudden event upsets. The resulting damage can range from temporary loss of instrumental operation to total loss of the satellite, and can run into losses of millions of dollars.

2. Objectives and methodology

The purpose of this work is to examine during Solar Proton Events (referred to here as SEP), the effects at geostationary orbit (6.6 Re), in relation to changes in other regions of the Sun-Earth system.

These SEP events are defined as a sharp and noticeable rise in the flux density of protons of energy 10-30 MeV observed at the ACE and the GOES satellites. These are found to be associated with multiple anomalies on satellites, generally occurring in quick succession. The space weather disturbance is traced right from its origin on the Sun(S); to its manifestations at the dayside Lagrangian point (L1 at 0.01 AU) in terms of solar wind parameters (Vsw, Nsw, Pressure Psw), the IMF parameters B, Bx, By, Bz and in the particles recorded on the SOHO-LASCO Coronagraph; to the changes in the Ne and Hp parameters recorded at the Geostationary orbit (G); to the changes at Earth surface (E) in the Dst, Kp indices and the Cosmic Ray Neutron Monitor (CRNM) count. The abbreviations S, L1, G, and E are used here because we are involved in modeling space weather effects at these regions.

There is another class of events referred to here as Proton Flux Enhancements (PFE), in which the number density of 1-5 MeV protons measured at the ACE and the GOES satellites shows a large change, but the change is not seen in the 10 - 30 MeV particles. These are also found to be associated with anomalies in satellites, but these occur in a smaller number (1, 2 or 3), and they are spaced apart in time. Hence we differentiate these from SEP, and refer to them as SFE events.

The space parameters as described above from Sun to Earth have been studied for all SEP and PFE during 2005. For purposes of brevity, some of these are listed in Tables 1 and 2, along with certain characteristic parameters. The figures which follow are shown for two typical cases of the two categories, namely the SEP of 22 Jan. 2005, and the PFE of 18 Feb. 2005. All other cases listed under the two categories, display roughly the same characteristics as the typical cases shown here. It is to be stated that the conclusions in this paper are based on raw data downloaded from relevant websites, with a view to understanding the basic phenomena in the events. Statistical treatment of the same is being presented in a forthcoming work.

3. Salient results

The main results from this work are depicted in Figs 1–8 which follow and are explained in the captions of the figures.

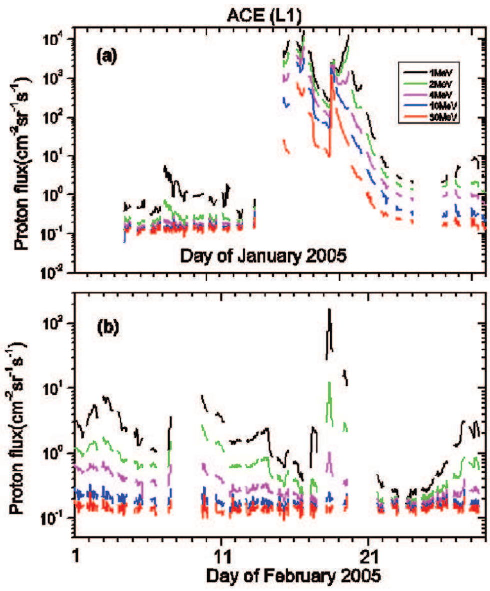


Figure 1. Solar Energetic Proton (SEP) events at the ACE satellite (L1 point) are seen at various energy bands, 1-5 MeV and 10-30 MeV. The SEP event of 16-25 January 2005 (a) showed very large enhancement in Proton Flux. In contrast the event of 17-22 February 2005 (b) measured at ACE satellite showed much lower enhancement in Proton Flux.

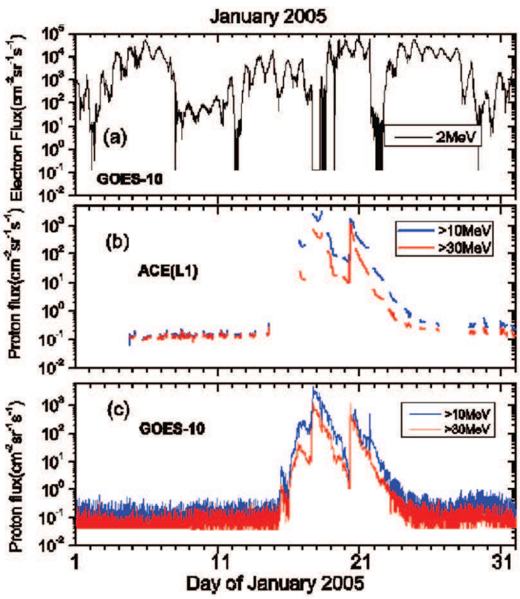


Figure 2. SEP events in 10-30 MeV Protons are seen at the Lagrangian point (L1) by the ACE satellite (shown in (b)), and also at the Geostationary orbit by the GOES-10 satellite (shown in (c)), when the Proton Flux at L1 exceeds 0.5 particle flux units (pfu also defined as particles/cm^2 sr.sec). Enhanced Proton Flux (10-30 MeV) over 16-25 January 2005 is 'followed' by enhanced flux of > 2 MeV Electrons at GOES-10 as shown in (a).

4. Conclusions based on data for 2005

SEP EVENTS (enhanced 10-30 MeV) FOR 2005

- SEP originate in very active regions on the Sun (of CME type), generally at solar longitudes of 65deg W to 65deg E. The SOHO-LASCO Coronagraph is flooded with particles during SEP.

- SEP are always observed at both L1 and G, whenever the flux of 10 MeV protons at the L1 orbit exceeds 0.5 pfu (particles/cm^2. sec. sr.)

- SEP at L1 and GOES are always found to be 'followed' by large ($> 10^3$ pfu and often exceeding 10^4 pfu) flux of > 2 MeV electrons at the GOES orbit. These are the 'killer electrons' which are responsible for Deep Dielectric Discharge effects on instruments aboard Geosynchronous satellites. We find that the anomalies occur in 'bunches' in rapid succession following SEP. Interpretations on these 'killer elec-

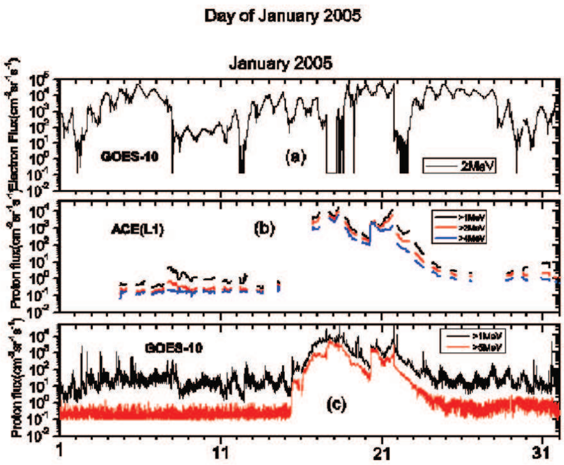


Figure 3. For reasons stated in text, we define an enhancement in 1-5 MeV protons as Proton Flux Enhancements (PFE). These are seen at both ACE (L1) shown in (b), as well as at GOES-10 (G) shown in (c), when the Proton flux at L1 exceeds 1 pfu. The PFE in 1-5 MeV protons during 1-8 Jan. 2005 and 15-31 Jan. 2005 are 'accompanied' by enhanced flux of >2 MeV electrons at GOES-10 shown in (a).

trons' have been given by Baker et al. (1994, 1998), Rostoker et al. (1998), and Liu et al. (1999)

- SEP at L1 and G are always associated with 'Sharp, well-defined' Shock structures at L1, with steep rise and drop in 1) the solar wind parameters Vsw, Nsw and Psw 2) the IMF parameters B, Bz, Bx, By. Characteristics of Solar Wind and IMF parameters during such Shock events have been discussed by Gopalswamy (2005).

- SEP are always accompanied by sharp large-magnitude Forbush decrease in the CRNM count (Forbush 1946), and a fairly rapid recovery thereafter. This could be because the 'sharp Shock' in Interplanetary space with very high trapped B field, first checks the entry of Galactic and Solar Cosmic Ray particles to Earth, and then permits entry of the same once the magnetic barrier dissipates. (Biswas 2000; Mc Cracken et al. 1962; Ness 1965; Venkatesan & Zhu 1990)

- SEP invariably trigger off an SSC type of magnetic storm in the Earth's magnetosphere, with the Dst minimum touching −100 nT and more. This is commensurate with a strong interplanetary shock hitting the dayside magnetopause.

- Kp invariably rises to values of 7 and more following SEP.

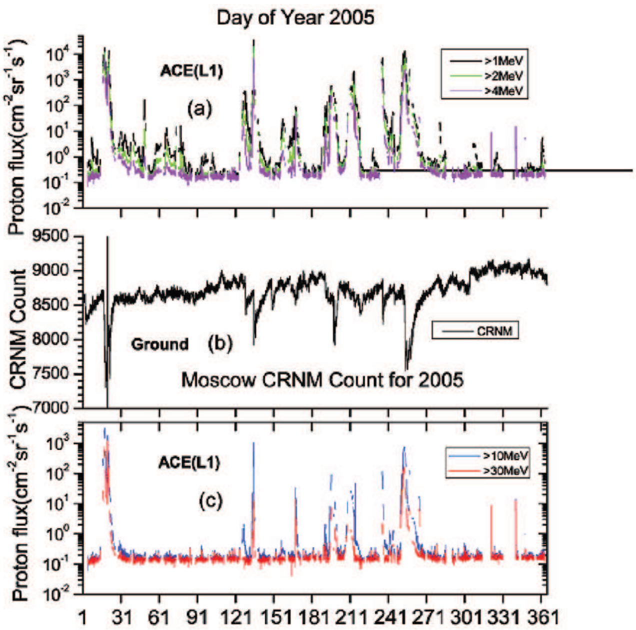


Figure 4. SEP events (10-30 MeV) recorded at the ACE (L1) satellite shown in (c) are reflected at Ground (shown in (b)) as major Forbush decreases in the Cosmic Ray Neutron Monitor Count (CRNM). When the PFE events (1-5 MeV) recorded at ACE(L1) shown in (a) are considered, these find correlations in even smaller Forbush-like decreases in CRNM count as shown in (b).

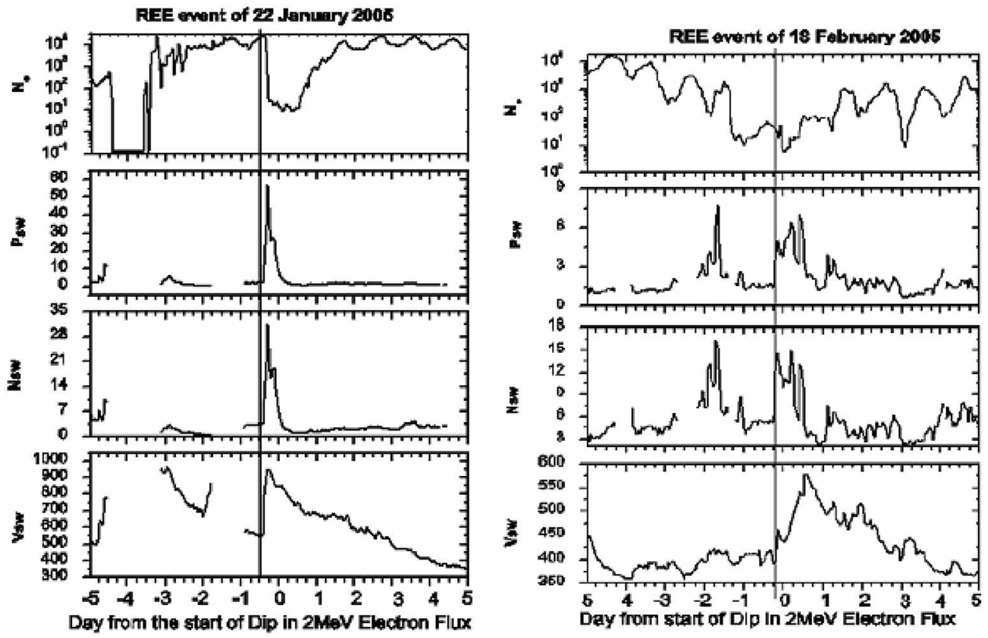
PFE EVENTS (enhanced 1-5 MeV) FOR 2005

- PFE are found to follow Coronal Hole (CH) and fast Solar wind Stream events on the Sun. There can be several Sunspots visible on the Solar disc at such times, but none of them are capable of imprinting any sizable number of particles in the SOHO-LASCO Coronagraph at L1

- Rise in 1-5 MeV proton flux occurs at both L1 and G when the flux of l MeV protons at L1 exceeds 1 pfu (particle/cm^2.sec.sr.)

- PFE at L1 and G are accompanied by 'diffuse poorly- defined' Shock structures at L1 i.e. there are increases in the IP parameters Vsw, Nsw and Psw and in the IMF parameters B, Bz, Bx, By, but they are not steep and intense; they are mostly of oscillating nature

- There are rises in the Ne flux of 2 MeV electrons at G during these PFE(1-5 MeV), but these are less spectacular than what is observed during SEP (10-30 MeV) (cf. Williams 1966). We find that PFE (1-5 MeV) are followed by lesser number of



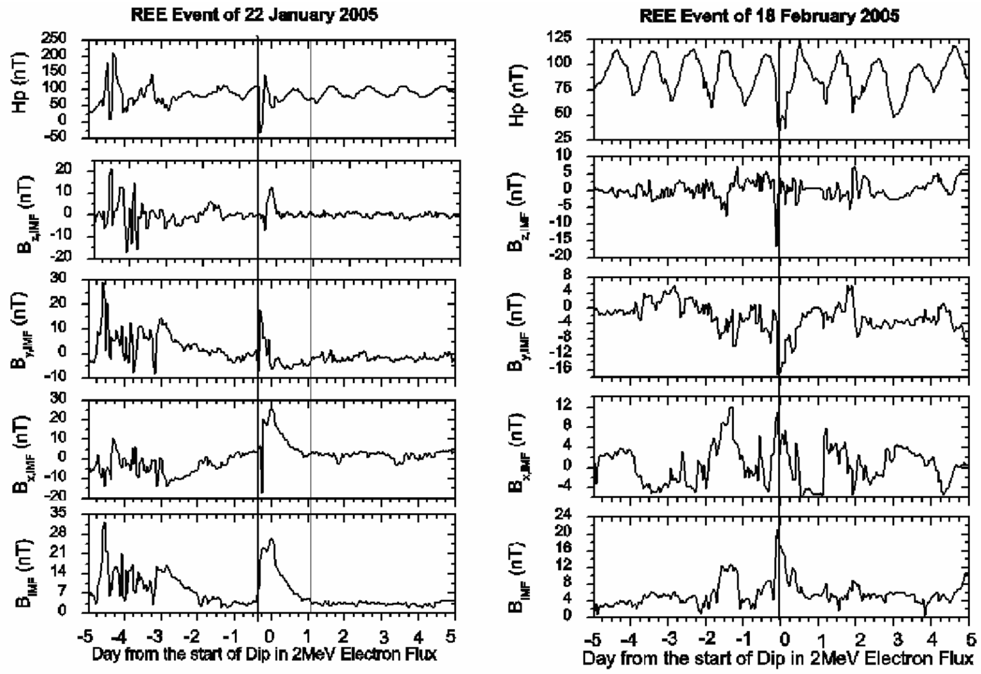
(a) (b)

Figure 5. (**a**) Ne flux (2 MeV), Solar wind parameters Vsw, Nsw and Psw are shown for 22 January 2005, for 5 days on either side of the zero denoting the sharp drop in Ne flux (known as RED or Relativistic Electron Dropout). Note that this sharp drop at geostationary orbit coincides with the sharp rise in the solar wind parameters at the Lagrangian point (L1). This sharp well-defined 'Shock' structure in the Solar wind parameters at L1 presents a way of predicting changes in Ne (2MeV) at G; we use this for predicting Satellite anomalies. (**b**) Ne flux (2 MeV), Solar wind parameters shown for 18 February 2005, for 5 days on either side of the Zero denoting the REE in Ne flux. Note that the diffuse drop in Ne at Geostationary orbit coincides with the diffuse rise in Solar wind parameters at the Lagrangian point L1, and is very different in nature from the sharp changes displayed by parameters in Fig. 5(a).

satellite anomalies (1, 2 or 3), spaced apart in time, not in quick succession as is seen during SEP.

- PFE are not accompanied by sharp Forbush decrease in the CRNM count as in the case of SEP. The drop and the recovery in the count during PFE are not as rapid as in the case of SEP. This is possibly due to the absence of strong Shock barriers of enhanced B, in interplanetary space, for PFE.

- The Dst index during PFE generally shows 'non SSC (storm sudden commence-



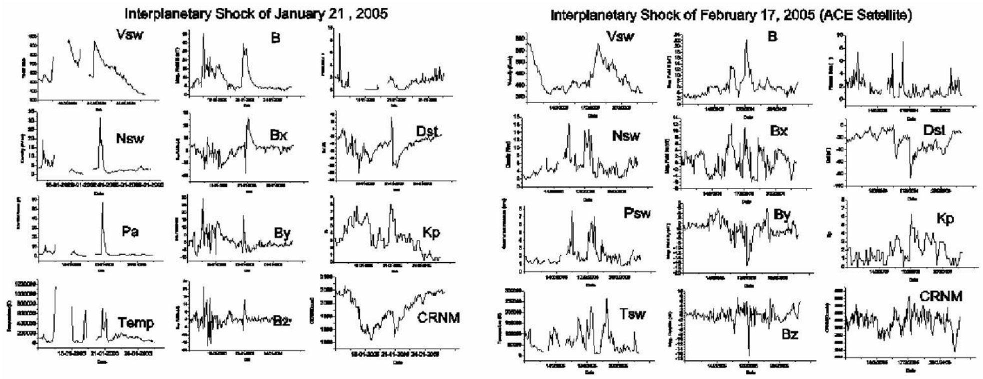
(a) (b)

Figure 6. (**a**) Magnetic field (Hp) measured parallel to the spin axis of the satellite GOES-10 at Geostationary orbit, and the Interplanetary B, Bx, By and Bz variations for the REE event of 22 Jan 2005. Note that the sharp drop and rise in Hp at zero time coincides with sharp changes in the Interplanetary magnetic field parameters. (**b**) Magnetic field(Hp) measured parallel to the spin axis of the satellite GOES-10 at the Geostationary orbit, and the Interplanetary B, Bx, By and Bz variations for the REE event of 18 Feb 2005. Note that the gradual drop in Hp at Zero time coincides with diffuse changes in the Interplanetary magnetic field parameters.

ment)' decreases, 'i.e. g.c. (gradual commencement)' type of storm changes; the index does not generally decrease below 80 nT for PFE events.

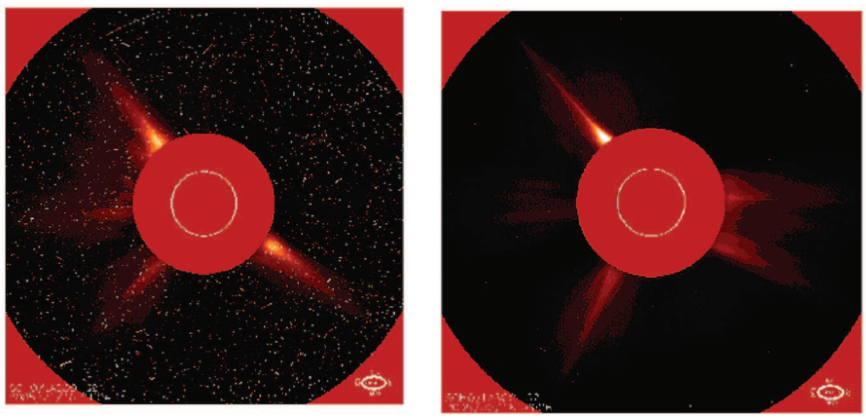
- Kp rises to values of 6 (generally not above this) for the PFE.

In final conclusion, SEP (10-30 MeV) and PFE (1-5 MeV) events, their attendant solar and Interplanetary/IMF manifestations at the L1 point, and their effects at the geosynchronous orbit (G) and Earth surface (E), are powerful indicators for predicting satellite operational anomalies. These indicators are being used by us for the purpose of such anomaly predictions.



(a) (b)

Figure 7. (**a**) Example of 'sharp well-defined' Shock at ACE (L1) seen in both solar wind and Interplanetary magnetic field parameters. Notice the sharp changes in the Ground-based geomagnetic indices Kp and Dst and the CRNM count which accompany the changes in the Interplanetary parameters. Such sharp, rapid changes in the CRNM count are associated with a particular pattern in anomalies observed on geostationary satellites at the same time. (**b**) This is an example of a 'less-defined, oscillating' Shock structure observed at L1 in both Solar wind and Interplanetary magnetic field parameters. In contrast to Fig. 7(a), the changes observed in the Dst, Kp indices and in the CRNM count are quite different, and the type of anomalies observed in Geostationary satellites too is found to be different.



(a) (b)

Figure 8. (**a**) On 18 Jan 2005 at 21:24 UT, note how the SOHO-LASCO coronagraph at L1 records a large number of SEP Protons following a Sharp Shock structure at L1. (**b**) On 18 Feb 2005 at 06:06 UT, note how during this less well-defined oscillating Shock structure at L1, hardly any SEP are monitored by the SOHO-LASCO Coronagraph.

Table 1. Solar proton events (10-30 MeV) seen at ACE (L1) and GOES (G)–2005.

S. No.	Period Observed		Solar Parameters		Effects at L1		Solar wind IMF change	2 MeV Flux at G	Geomagnetic changes at Earth (E)
–	L1	G	Lat/Long AR	Type of Flare	SOHO/LASCO	Shock date	IMF change	–	–
1.	14-25 Jan. '05	16-24 Jan. '05	AR720 N13W30 18 Jan. '05	X & M flares 18 Jan. '05	Large no. of SEP	21 Jan. '05 16:48 UT	Sharp well-defined	$> 4 * 10^4$ pfu	ssc Storm sharp steep CRNM drop
2.	6-9 May '05	6-9 May '05	AR758 S06E37 6 May '05	M & C flares 6 May '05	No SEP observed	No shock time	–	$> 10^4$ pfu	–
3.	14-17 May '05	13-17 May '05	AR759 N12E12 15 May '05	M flares 15 May '05	Large no. of SEP (full halo CME)	15 May 02:19 UT	Sharp well-defined	$> 10^5$ pfu	ssc storm sharp steep CRNM drop
4.	16-20 Jun '05	16-18 Jun '05	AR779 S18W19 18 Jun '05	M/C/B flares 18 Jun '05	No data	No shock time	–	$> 4^*10^3$ pfu	Minor drop in Dst CRNM (no data)
5.	10-11 July '05	10-11 July '05	AR786 N09E03 10 July '05	M flare 10 July '05	No data (full halo CME)	10 July '05 02:56 UT	Diffuse oscillating	$> 2^*10^3$ pfu	Sharp drop in Dst, CRNM diurnal variation

Table 2. Solar flux enhancements (1-5 MeV) seen at ACE (LI) and GOES (G).

S. No.	Period observed		Solar feature sunspots present	Effects at L1		2 MeV flux at G (pfu)	Geomagnetic changes at Earth (E)
	L1	G		SOHO LASCO	Solar wind, IMF change		
1.	7 Jan. ′05 12 Jan. ′05 30 Jan. ′05	√	CH Reported	Very few SEP		$\sim 2^*10^4$ $\sim 5^*10^3$ $\sim 2^*10^3$	
2.	Feb. ′05 3, 8 16, 18	√	CH Reported	Very few SEP	Diffuse oscillating	$\sim 5^*10^3$ $\sim 5^*10^2$ $\sim 7^*10^3$ $\sim 4^*10^2$	
3.	Mar ′05 7, 15 18, 20 25	√	Fast solar Wind stream Reverse Shock 16:40 UT	Very few SEP	Diffuse oscillating	$\sim 3^*10^4$ $\sim 5^*10^2$ $\sim 2^*10^2$ $\sim 2^*10^3$ $\sim 10^2$	Diffuse changes in Dst. CRNM shows diurnal pattern
4.	Apr. ′05 7/12 13	√	CH Reported	Very few SEP	Diffuse oscillating	$\sim 2^*10^4$ $\sim 2^*10^4$ $\sim 9^*10^3$	Clear drop in Dst, CRNM shows diurnal pattern
5.	May ′05 8/28 29	√	Shock 03:48 UT Shock 09:15 UT	Very few SEP	Fairly sharp but data missing	$\sim 2^*10^2$ $\sim 5^*10^3$ $\sim 10^2$	Multiple drops in Dst
6.	Jun ′05 7, 12	√	Shock 06:59 UT	Very few SEP	Fairly sharp but data missing	$\sim 2^*10^4$ $\sim 8^*10^2$	CRNM oscillating, Dst sharp drop

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