3.10 Solar energetic particles effect on the Earth/ionosphere in quiet geomagnetic condition

Paul J Marchese, Donald E. Cotten *, and Tak David Cheung
City University of New York Queensborough Community College

1. Abstract

High speed coronal mass ejection CME events with fast solar energetic particles SEP are identified using the LASCO-SOHO coronagraph and GOES proton flux data (>10 Mev) respectively. The fast SEP could be produced when the high speed CME shock front collides with the preceding CME. This project focuses on those SEP events when the storm disturbance index Dst is higher than -80 nT, that is, relatively quiet geomagnetic field period with no geomagnetic storm. The ionosphere response to these events is detectable by the TEC and normalized foF2 indices. Deviation of ionosphere TEC of 70% of the 30-day median was observed. A correlation coefficient of 0.97 between the TEC deviation and proton flux in quiet storm condition was found when the TEC ratio was normalized to the surrounding 30-day median. The success of a storm prediction model that uses quiet day ionosphere index would be affected by perturbation of the baseline by the SEP events, and the details would depend on the baseline subtraction criteria used. The terrestrial gamma ray flash produced by one such event (Dst about -40 nT) was captured by RHESSI (04-21-2002). The reported observation of atmospheric bremsstrahlung is found to be related to a smaller ionospheric response. The correlation result might be used to check the interacting CME speed and therefore forecast its arrival time at Earth in quiet geomagnetic condition.

2. Introduction

Geomagnetic storm prediction models for the ionosphere-magnetosphere usually rely on quiet day condition as its baseline reference. Examples include the storm model proposed by NOAA at Boulder, Colorado, USA (Araujo-Prasere 2002) and Rutherford Appleton Laboratory, UK (Cander 2002). It is well accepted that coronal mass ejection (CME) events could produce large geomagnetic storms. It is also well accepted that solar energetic particles (SEP) accompany some CME events. High speed coronal mass ejection CME events with fast solar energetic particles SEP are identified using the LASCO-SOHO coronagraph and GOES proton flux data (>10 Mev) respectively. NOAA listed the high energy (>10 Mev)proton flux rate on the internet. One such event, 4-21-2002, produced a peak flux of 2520 pfu (from NOAA listing).

* Affilation: (DEC) City University of New York Space Science Research Alliance, (PJM & TDC) City University of New York Queensborough Community College, email: decotten@aol.com, pmarchese@qcc.cuny.edu, tcheung@qcc.cuny.edu.

The associated terrestrial gamma flash was measured by RHESSI while the Dst is about –40 nT with a TEC (total electron content) value about 70% of the monthly median. The contribution of the SEP to the ionosphere response could be distinguishable from the interplanetary magnetic field contribution in other events. This project focused on the high energy proton events with Dst > 80 nT, that is, relatively quiet geomagnetic condition.

3. Data and Analysis

The data for >10 Mev proton events with high Dst values were selected. A criterion was –80 nT or higher in the Dst index. The Dst data source was internet address http://swdcdb.kugi.kyoto-u.ac.jp/Dstdir. The TEC data was from http://ionosphere.rcru.rl.ac.uk/medians.htm

The proton flux and dates were from NOAA website http://www.sec.noaa.gov/Data/

The CME data was from http://cdaw.gsfc.nasa.gov/CME_list/

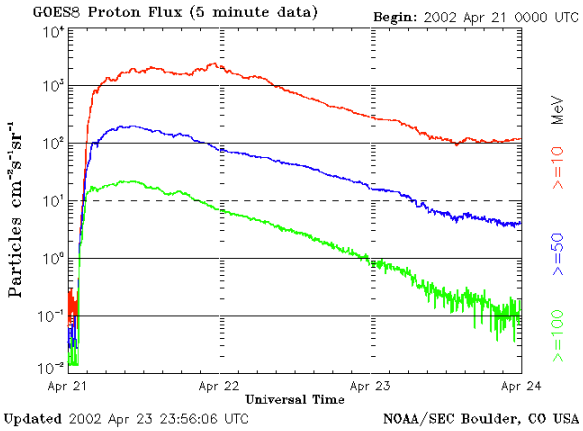
Date(2002)	proton flux (pfu)	Dst
11-Jan	91	-65 nT
23-May	820	-72 nT
17-Jul	234	-4 nT
22-Aug	36	-25 nT
7-Sep	208	-77 nT
10-Nov	404	-22 nT
21-Apr	2520	-41 nT

The Dst value was selected to be the lowest value within a 3-hour interval of the maximum SEP flux to ensure quiet geomagnetic condition.

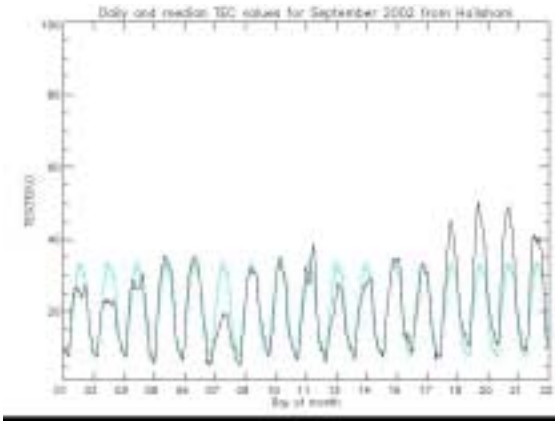
The Aug 24, 2002 event had a proton maximum flux of 317 pfu. This SEP event was not used in this study because the associated TEC data was uncertain. The March 19 2002 SEP event had a proton maximum flux of 53 pfu. This SEP event was not used in this study because the associated CME speed was uncertain.

The flux posted on the NOAA website corresponded to the peak value.

A typical GOES proton flux event is shown here.



A typical TEC graph from Halisham (Long 0, Lat 50). A larger graph is shown in the appendix for clarity.



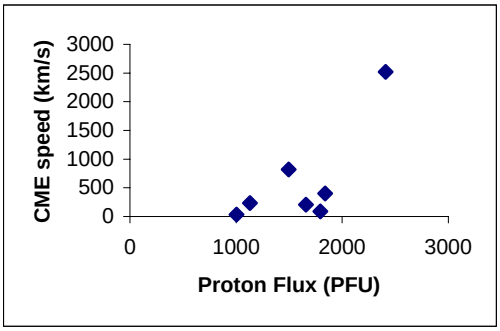
TEC ratio (observed/monthly median) values from Hailsham station are listed in the following table. The maximum values were used. Note that the July data was obtained from the associated hourly plot because the monthly plot was missing.

TEC ratio	Date(2002)	proton flux
0.727273	11-Jan	91
1.428571	23-May	820
0.608696	17-Jul	234
1.2	22-Aug	36
0.5625	07-Sep	208
1.428571	10-Nov	404
0.690476	21-Apr	2520

The CME data is listed in the following table.

Date(2002)	Speed (km/s)
11-Jan	1794
23-May	1494
17-Jul	1132
22-Aug	1005
07-Sep	1657
10-Nov	1838
21-Apr	2409

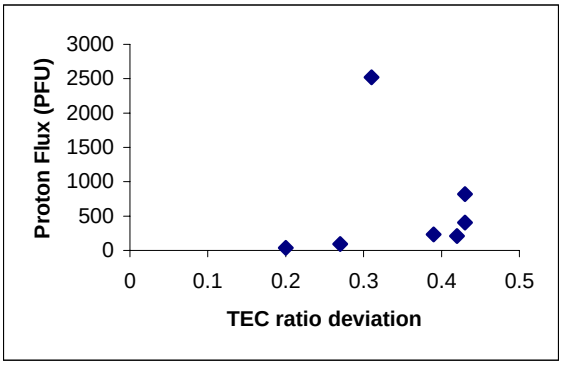
The following is the graph of CME speed versus proton flux. The correlation coefficient is about 0.75.



The graph of CME speed (y axis) versus proton flux (x-axis).

The graph also suggested that there might be possibly two statistical categories of CMEs with associated SEP production.

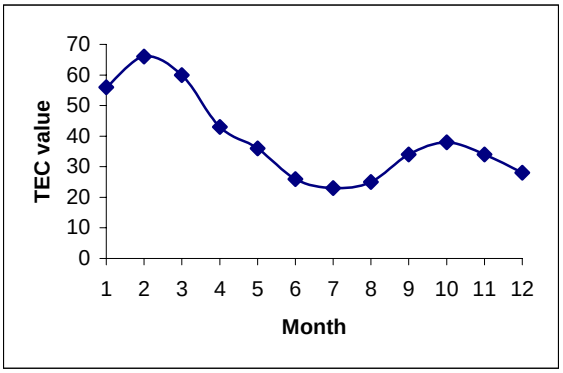
The graph of TEC ratio deviation, the absolute value of (1- TEC ratio), using calendar monthly median versus proton flux is shown in the following.



The proton flux versus TEC ratio deviation (absolute value) graph.

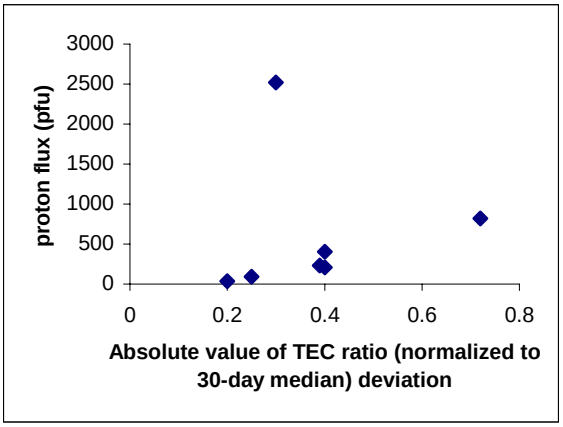
There was much scattering in the data points. On the other hand, the TEC ratio could be defined as the observed TEC normalized to the 30-day median instead of the calendar monthly median. A plot of the

maximum monthly median versus time is shown in the following graph.



The maximum monthly median TEC value graph starting with January 2002 as 1 in the x-axis.

The 30-day median for a given day was extrapolated from this monthly median graph. A new graph showing Absolute Value (1- TEC observed normalized to the 30-day median) versus proton flux was generated.

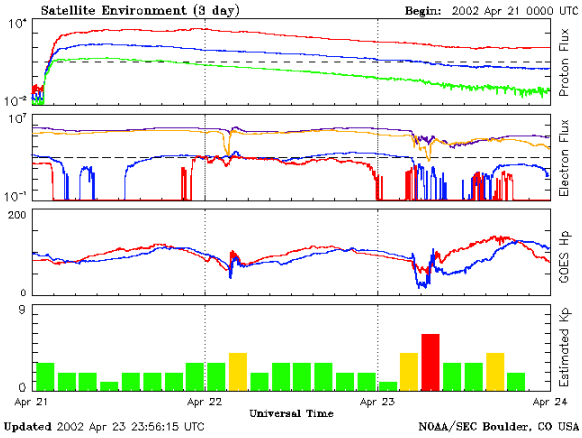


Proton flux versus Absolute Value (1- TEC observed normalized to the surrounding 30-day median)

The (0.3, 2520) data point (April 2002 event) was an obvious outlier (to be discussed later). The correlation for the remaining 6 data points was 0.97 suggesting a strong correlation of SEP flux and the deviation of the TEC value normalized to a 30-day median. The slope was 1524 unit and the intercept was –300 unit. The inclusion of the (0,0) point would suggest that the graph could be represented by a second-degree polynomial. Nevertheless, the linearity appeared to be applicable from 30 to 1000 pfu range.

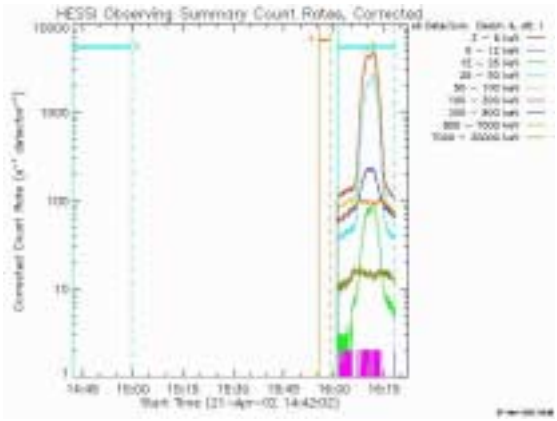
The (0.3, 2520) data point should be excluded because this event produced a terrestrial gamma ray flash as recorded by RHESSI. Thus the SEP had an alternative channel for energy dissipation and might account for the low deviation of TEC value.

The GOES satellite environment data for the 4/21/2002 event is shown :



The lower graph clearly showed that the geomagnetic condition was quiet.

The RHESSI data for the 4/21/2002 event is shown.



A larger graph is shown in the appendix for clarity. This event generated a high annihilation flux at 511 kev and a power law continuum from atmospheric bresmsstrahlumg (Share 2003). The reported observation of atmospheric bremsstrahlung (April 2002 event) is found in the preceding graph to be related to a smaller ionospheric response than would be expected from the correlation. This large energy deposition in alternative channels may explain a limited impact of the SEP on the TEC ratio.

4. Discussion

The data revealed that CME speed has a correlation of 0.75 with proton count peak rate. A correlation coeficient of more than 0.9 between the TEC deviation and proton flux in quiet storm condition was found when the TEC ratio was normalized to the surrounding 30-day median. The linearity was applicable to the range of 30 to 1000 pfu. The terrestrial gamma ray flash signal detected by RHESSI was an example of an alternative channel for energy deposition. The success of a storm prediction model that uses quiet day ionosphere index would be affected by perturbation of the baseline by the SEP events, and the details would depend on the baseline subtraction criteria used. The associated CME speeds were from 1000-2000 km/sec and the arrival time would be about 15-30 hours.

5. Conclusion

This project reveals a correlation (above 0.9) between the deviation of TEC values and the high energy (> 10 MeV) proton flux. The TEC value was normalized to the 30-day median instead of the calendar monthly median. The quiet day baseline in storm prediction model would be affected depending on the flux of the SEP. Alternative energy deposition channels such as the terrestrial gamma ray flash would reduce the impact on the TEC value. This exploratory study could be extended to include the latitude dependence of the SEP effect on the ionosphere under quiet geomagnetic condition so that a comprehensive global baseline for storm models could be established.

6. Acknowledgements

We thank Dr. Leon Johnson for discussion on this project, he and NASA Grant NAG-5-10142 for student support and for helpful discussion. We also thank Dr. Shermane Austin (NASA/MU-SPIN NCC 6-530) for helpful suggestions. Dr. Cotten serves in the City University of New York NYC Space Science Research Alliance (NAG-5-10142). Drs. Marchese and Cheung serve in the City University of New York Queensborough Community College Physics Department.

The CME catalog used in this project is generated and maintained by NASA and The Catholic University of America in cooperation with the Naval Research Laboratory. SOHO is a project of international cooperation between ESA and NASA.

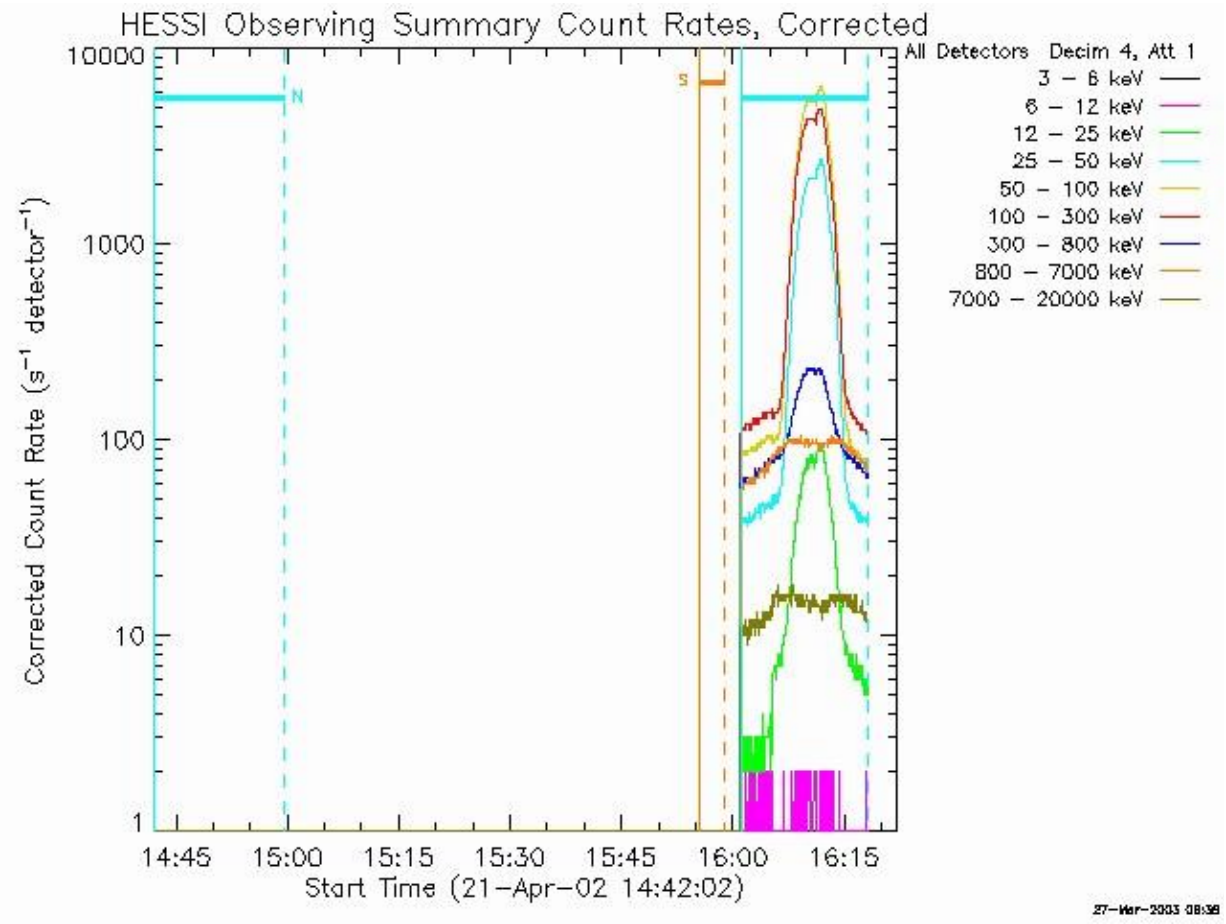
7. References:

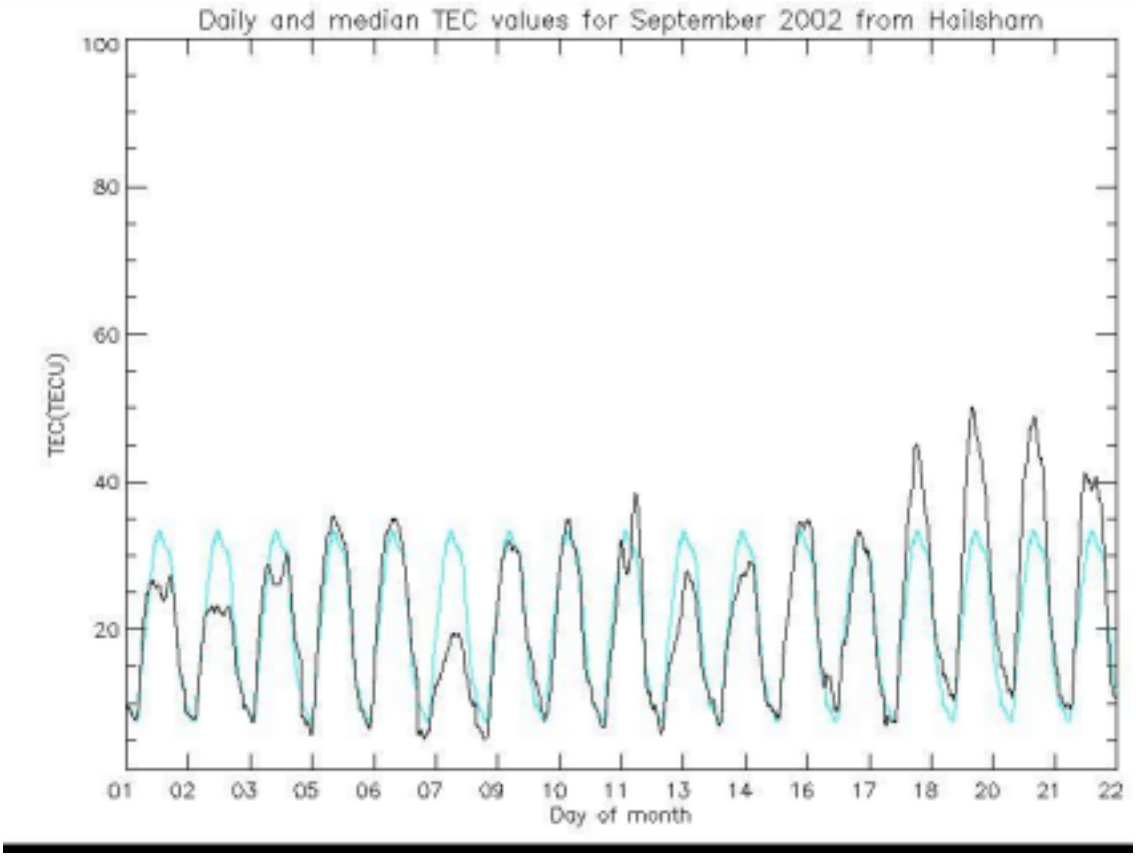
Araujo-Prasere E.A. (2003), Fuller-Rowell T.J, : Storm: an empirical storm-time ionospheric correction model 2, validation, Radio Science, vol 37, no10, 1029-1042

Cander L. R. (2002), Belehaki, A. and Tsagouri, I, : Real time dynamic ionospheric storm modeling, http://ionosphere.rcru.rf.ac.uk

Share G.H. (2003, Murphy R.J., Dennis B.R., Schwartz R.A., Tolbert A.K., Lin R.P., Smith D.M., : RHESSI Observation of Atmospheric Gamma Rays from Impact of Solar Energetic particles on April 21, 2002. in press

8. Appendix


HESSI Observing Summary Count Rates, Corrected
All Detectors Decim 4, Att 1
3 – 6 keV
6 – 12 keV
12 – 25 keV
25 – 50 keV
50 – 100 keV
100 – 300 keV
300 – 800 keV
800 – 7000 keV
7000 – 20000 keV
Corrected Count Rate (s⁻¹ detector⁻¹)
10000
1000
100
10
1
N
S
14:45
15:00
15:15
15:30
15:45
16:00
16:15
Start Time (21–Apr–02 14:42:02)
27–Mar–2003 08:38


Daily and median TEC values for September 2002 from Hailsham
TEC(TECU)
100
80
60
40
20
01
02
03
05
06
07
09
10
11
13
14
16
17
18
20
21
22
Day of month