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The CME-index for short-term estimation of Ap geomagnetic index based on the new ICME list

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Abstract: It is well known that the interplanetary coronal mass ejections (ICMEs) play the most important role on their interactions with the magnetosphere as they are the dominant drivers of intense geomagnetic storms. In this work 160 ICMEs associated with CMEs were spotted from SOHO-LASCO coronagraph and their characteristics were calculated by in situ observations from ACE data. The result of this analysis is a new ICMEs list which contains all the available information for the background geomagnetic conditions before the arrival of the shock, the sheath between the shock and the main part of the ICME and the ICME itself, such as velocities, magnetic fields (B_{sheath}, B_{ICME} and B_z) and plasma characteristics (plasma β, temperature and density) and the geomagnetic conditions, such as the Dst index minimum and the Ap maximum values. This new ICME list has been used for the formation of the CME-index (P_i) taking into account for the first time the magnetic field of these ICMEs and other characteristics as well, such as their angular width and their velocity. These ICMEs characteristics show a very high correlation between the examined variables, such as the magnetic field z component (Bz) and the Dst minimum value, during the geomagnetic storm or the mean magnetic field of the sheath and the transit velocity of the ICME, revealing important results. At this point a model based on the CME-index created from this list is proposed in order to predict geomagnetic conditions and especially the Ap index and it is tested in some case studies with very good results.

1 A new ICMEs catalogue

Interplanetary coronal mass ejections (ICMEs) and high speed streams of solar wind emanating from coronal holes are the dominant factors for geomagnetic storms. Previous studies have shown that intense geomagnetic storms are mainly caused by ICMEs, while moderate and minor storms can be caused by both ICMEs or high speed streams of solar wind ([1] and references there in). These interplanetary CMEs (ICMEs) are varied with shocks or without shocks, magnetic cloud structures with smooth magnetic field rotations, low temperature and proton density etc. There is a number of ICMEs lists with a lot of information about these events such as [2], [3] and [4].

In this work we developed a new ICMEs list covering the years 1996-2009 and taking into account solar wind plasma and magnetic field observations by in situ observations from the Advance Composition Explorer mission (ACE) for the background conditions before the arrival of the ICME, for the sheath and for the main part of the ICME, is developed. In the sheath there is information for the arrival time of the shock/disturbance and the shock presence or not. In the main ICME part there is information for the start/end time of the ICME, the magnetic cloud structure, the magnetic fields, the mean and maximum velocities, the transit velocity of the ICME, the proton temperature, the proton density, the alpha particles to proton ratio, the calculated plasma β, the Dst index minimum and Ap index maximum values during the associated geomagnetic storm and the possible solar flare connection. These information are available for each CME for the first time in one catalogue.

The new perspective of this list could be divided into two major contributions: a) all of 160 events were associated with CMEs which spotted firstly by SOHO/LASCO coronagraph and as a result for the first time is possible to have as many as possible information for a CME from the first time which have been spotted, up to the time arrival at Earth and for the entire duration of the event using

ACE mission (MAG-SWEPAM data), and b) these ICMEs were used to calculate the CME-index [5] values based on a new equation taking into account for the first time the magnetic field and the transit velocity of the ICME. Finally, these values were used in order to develop a new exponential model for the estimation of Ap geomagnetic index [6].

2 Data selection

For the present study data from the Large Angle and Spectrometric Coronograph (LASCO) on-board the Solar and Heliospheric Observatory (SOHO) covering the time interval from 1996-2009 were used. In particular, data for the CMEs were taken from the SOHO/LASCO CME catalog 'http://cdaw.gsfc.nasa.gov/CME_list/'.

Magnetic field and plasma data such as proton temperature, proton density and alpha particles to proton ratio were taken from the 64-second averages of Advance Composition Explorer (ACE) mission 'http://www.srl.caltech.edu/ACE/ASC/level2/lvl2DATA_MAG-SWEPAM.html'.

The calculations for plasma β were based on the ACE data. Data for the Ap and Dst indices were taken from the OMNI database 'http://omniweb.gsfc.nasa.gov/form/dx1.html'.

3 An Ap estimation model

For the current study from the total number of 160 ICMEs, 26 events which caused geomagnetic storms with minimum Dst index less than -150 nT, were used for analysis. These events were associated with 7 C-, 8 M- and 11 X-class solar flares. Especially 12 of these events produced the most intense geomagnetic storms with Ap geomagnetic index 3-hour maximum value greater or equal of 300. These geomagnetic storms caused by CMEs with high transit velocities $V_{tr} = 1250$ km/s, high magnetic field values B = 17.8 nT, accompanied by M-class or X-class solar flares and almost all had magnetic cloud (MC) structure characteristics with smooth magnetic field rotations. As we mentioned before the 26 events were used for the calculations of CME-index (P_i) taking into account the mean magnetic field B, the transit velocity and the angular width of the CME based on the equation:

$$P_i = \frac{B}{B_{max}} + \frac{V_{tr}}{V_{max}} + \frac{w}{360^\circ} \tag{1}$$

where B_{max} is the maximum value of the magnetic field of the examined events, V_{max} is the maximum transit velocity and 360° refers to the HALO CMEs, and as a result this index has dimensionless values.

At this point we should mention that we have developed a code which actually takes into account the perihelion and the aphelion of the Earth for the current date of each event in order to define the distance of Earth from the Sun. The duration of the CME which takes to reach Earth defined from the start time according SOHO/LASCO list and the arrival time of the shock/disturbance which defined from the ACE data. From these data the transit velocity of the ICME was calculated.

The maximum value of P_i-index ($P_i = 3$) was noticed for the Halloween event of October 28, 2003 at 11:30 UT (CME spotted in LASCO coronograph) as this CME was a HALO event associated with a powerful X17.2 solar flare which caused an extreme G5 geomagnetic storm. This event had a mean magnetic field value of 31.7 nT and a transit velocity of 2235.1 km/s. The sheath of this event had very high values of magnetic field with $B_{max} = 63.3$ nT and Bz component of -60.8 nT. The P_i-index values which based on Eq. (1) were used in order to estimate the Ap geomagnetic index values. As it is obvious the present study could give very important results from the development of a model which will be able to estimate the Ap geomagnetic index values based on solar extreme events which are the most important ones on the space weather conditions. Finally, an analysis of these results gave a new relation for the geomagnetic Ap index through the values of P_i-index according to the following exponential model:

$$Ap = A_0 + A \cdot e^{R_0 \cdot P_i} \tag{2}$$

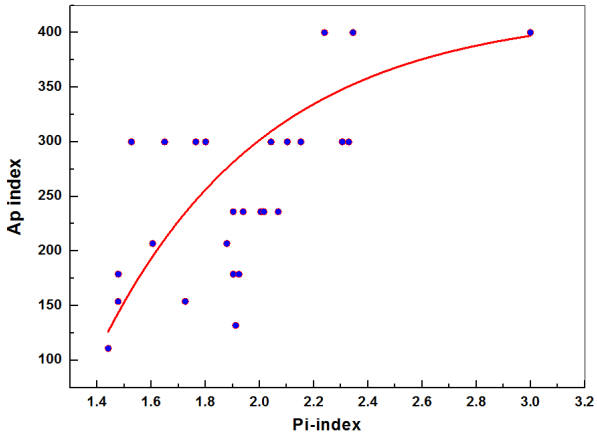


Figure 1: The observed geomagnetic Ap index values and responding Pi-index values calculated by Eq. (1) for each of the examined events. The best fit is an exponential model (red line).

where Ap is the calculating value of Ap index which is the dependent variable, A_0, A and R_0 are the constants 420.5, -3043.3 and -1.622 respectively and P_i is the P_i-index value which is the independent variable (Fig. 1).

For the previous event of the CME of October 28, 2003 at 11:30 UT, the Pi-index was found to be 3.00 and the estimated Ap index value from the Eq. (2) was 400. This is an absolute approximation as the observed value of maximum 3-hour Ap being 400 at the 06:00-09:00 UT of October 29, 2003 during this strong G5 geomagnetic storm. The results of this approximation revealed that 10 out of the 26 events had a variation less than 10% between the observed and calculated Ap values, 5 events had a variation between 10% and 20%, 5 events had a variation between 20% and 30%, 4 events had a variation between 30% and 40% and only 2 events had a variation greater than 40%.

4 Conclusions

In this work a new comprehensive and fully detailed catalogue of ICMEs was used and a selection of 26 out of 160 events with Dst index less than -150 nT were studied. For the most intense geomagnetic storms the 3-hour maximum of the Ap geomagnetic index reached the value of 300 and for the most extreme events it was equal to 400. The main findings of this study are summarized as follows:

- We used a new ICME catalogue of 160 events with as many as possible information (magnetic fields, solar wind and plasma parameters) before the arrival, during the sheath and finally the main part of the ICME. All of these events are spotted by SOHO/LASCO coronagraph and analyzed using in situ observations from ACE mission. We also inestigate the possible solar flare connection of these events and the effects on the Earth's magnetosphere when the ICMEs arrived on Earth giving the maximum 3-hour value of Ap geomagnetic index and the minimum Dst index value. All these information are presented in one catalogue for the first time.

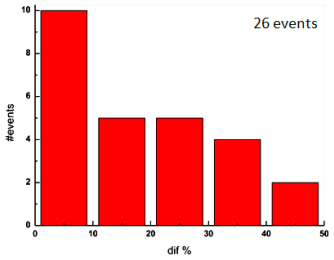
- All of the selected for study events were associated with 7 C-, 8 M- and 11 X-class solar flares. Almost all had a magnetic cloud structure with smooth magnetic field rotations.

- For the most intense geomagnetic storms the mean value of magnetic field and transit velocity of the associated ICMEs was 17.8 nT and 1250 km/s respectively. These values are in higher levels when the mean value of background conditions before the arrival of the ICME was 7.96 nT and 455 km/s respectively.

- The calculated values of Pi-index from Eq. (1) ranged from 1.44 up to 3.00 for the extreme event of October 2003. These values were used in order to develop a new estimation model of Ap geomagnetic index.

Variation $(Ap_{calc} - Ap_{obs})/Ap_{obs}$ (%)	
< 10 %	10
< 20 %	5
< 30 %	5
< 40 %	4
> 40 %	2

Variation $(Ap_{calc} - Ap_{obs})/Ap_{obs}$ (%)	
< 10 %	8
< 20 %	1
< 30 %	2
< 40 %	3
> 40 %	4



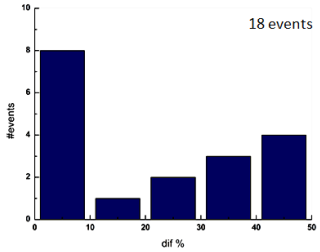


Figure 2: The allocation of the events according the percentages of the variation between the observed and estimated values of geomagnetic Ap index of the current work (left column) and the previous one (right column). It is obvious that our new model presents a better allocation in contrast to that one presented in [6].

- The values of the Ap index as they calculated from the exponential Eq. (2) are in accordance with the observed ones. Especially 10 events had calculated Ap values very close to the observed ones with a variation less than 10%. The other cases have a variation from 10% to 40% but only two events had variation greater of 40%. This new model show a better allocation of the events than our previous one [6].

The proposed method will be useful for Space Weather studies as it is based on the most extreme events which are the dominant factors of intense geomagnetic storms.

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References

[1] Zhang, J., Richardson, I. G., Webb, D. F., Gopalswamy, N., Huttunen, E. et al.: 2007, J. Geophys. Res. 112, A10102.

[2] Jian, L., Russell, C.T., Luhmann, J.G. and Skoug, R.M.: 2006, Solar Phys. 239, 393-436.

[3] Richardson, I.G. and Cane, H.V.: 2010, Solar Phys. 264, 189-237.

[4] Mitsakou, E. and Moussas, X.: 2014, Solar Phys. 289, 3137-3157.

[5] Paouris, E.: 2013, Solar Phys. 284, 589-597.

[6] Paouris, E., Gerontidou, M. and Mavromichalaki, H.: 2013, Proc. 11th HEL.A.S. Conf.