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Using the CME-index for short-term estimation of Ap geomagnetic index

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Abstract: It is known that the long-term cosmic ray modulation is anticorrelated with a significant parameter of solar activity, the coronal mass ejections (CMEs). In order to investigate this anticorrelation, a new index named P_i-index which improved very well the reproduced cosmic ray intensity, has introduced. The present work is intended to examine this index from a new perspective applied to the short-term estimation of the geomagnetic index Ap. A preliminary attempt to relate the main characteristics of CMEs such as the angular width and the linear velocity with the Ap geomagnetic index values shows a good approximation to the geomagnetic conditions after extreme events associated with CMEs and energetic solar flares. The results of this study can be useful for the estimation of the geomagnetic Ap index and can be considered as a first effort for short prediction of the geomagnetic conditions based on the index of CMEs.

1 Introduction

In the study of solar-terrestrial relationships, it is generally desirable to have some estimate of the level of dissipation of energy within the magnetosphere at any given time. This need led to a series of indices which designed to give a semi quantitative measure of the level of magnetospheric activity. The four most commonly used indices are Kp, Ap, AE and Dst [1]. For this research Ap index selected to be studied in relation with P_i-index as this index is commonly used from the scientific community for the purposes of arithmetic manipulation as it is more convenient to use an index based on a linear scale rather than on a quasi-logarithmic scale as Kp denotes. Accordingly [2] introduced the daily equivalent planetary amplitude, Ap, which is the average of the eight ap values computed for each 3-hour interval. The 3-hour index ap is obtained directly from Kp and hence it is based only on mid-latitude observations [1].

In a previous work dedicated on CME-index (P_i), the relation of this index with the cosmic ray (CR) intensity was established [3]. This index have improved all the empirical models of galactic cosmic ray modulation with the best of them taking into account the sunspot number, the interplanetary magnetic field, the tilt angle of the heliospheric current sheet and the P_i-index. The standard deviation between the observed and calculated CR intensity values was found to be about 6.6% [4]. This result is important for short and/or long-term cosmic ray modulation studies or space weather studies, due to the fact that this index is strongly connected to extreme events and not only to the overall solar activity as the sunspot number does [3]. Another argument which supports this point of view is the fact that in this work have been studied also the linear fit between: a) the Ap geomagnetic index with sunspot number and a correlation coefficient found of r = -0.47 and b) the Ap geomagnetic index and P_i-index and a correlation coefficient found of r = -0.68 for the examined period of 1996-2013, showing the relationship of Ap index with CMEs rather the sunspot numbers.

From this point of view a new research studying the relation of this index to events strongly connected with CMEs and produced finally strong geomagnetic storms has been developed.

As it is well known a geomagnetic storm is the consequence of a chain of causative events originating from the Sun and ultimately evolving into a geoeffective solar wind flow in near-Earth space ([5] and

references there in). Previous studies have found that major/intense geomagnetic storms (e.g., Dst>100 nT, or Kp>7) are mainly caused by interplanetary CMEs (ICMEs) ([5] and references there in).

In this work the association between geomagnetic storms having daily geomagnetic index Ap greater than 100 and CMEs for a long time period covering the span 1996-2013, has been studied. For this period twenty two events with daily Ap greater than 100 have been found, while twenty of them were connected with very powerful CMEs. Finally, a connection between Ap values and P_i-index ones is established.

2 Data Collection

For the present study data from the Large Angle and Spectrometric Coronograph (LASCO) onboard the Solar and Heliospheric Observatory (SOHO) covering the time interval from 1996-2013 were used. In particular, data for the CMEs were taken from the SOHO/LASCO CME catalog (http://cdaw.gsfc.nasa.gov/CME_list/). Data for the Ap index were taken from the National Geophysical Data Center:

(ftp://ftp.ngdc.noaa.gov/STP/GEOMAGNETIC_DATA/INDICES/KP_AP/).

3 Estimation of Ap index through P_i-index

The new perspective in this work is the study of the appeared maximum values of the geomagnetic Ap index during geomagnetic storms and the association with the values of P_i-index using data from the CMEs which caused these storms. Firstly, 20 events with daily Ap index > 100 which caused by CMEs were studied. Different characteristics, such as the connection of these CMEs with solar flares, the arrival time of the shock, the linear speed, the angular width and the time of the CMEs, based on the Table 1 of the work [5] have been taking into account for this study. For the present work this table has been supplemented with the maximum value of the Ap index during the storm and the time of this maximum.

Secondly, the analysis of these twenty events has shown that these events are divided into two major categories, named S-type and M-type events. The S-type events are those ones where the geomagnetic storm is associated with a single ICME and/or a single CME at the Sun. On the other hand the M-type events are those ones where the geomagnetic storm is associated with a complex solar wind flow produced by multiple interacting ICMEs arising from multiple HALO CMEs launched from the Sun in a short time window. More than half of the events (11) were S-type and the other nine ones were M-type. Most of these events (16) were strongly connected with energetic solar flares of M-class and X-class solar flares. Especially 10 events (5 M-type and 5 S-type) were connected with X-class solar flares, 6 with M-class (3 M-type and 3 S-type), 2 with C-class (2 S-type) and 2 with no flare (1 M-type and 1 S-type).

As it is already mentioned, in this study the CME-index was used in order to estimate the Ap-index values. In previous works [3], the P_i-index was defined using the monthly number of CMEs and the mean linear speed of these events according to the relation:

$$P_i = \alpha \cdot \frac{Nc}{Nc_{max}} + \beta \cdot \frac{Vp}{Vp_{max}} \tag{1}$$

where Nc is the monthly number of CMEs and Vp is the mean linear speed of CMEs. Nc_{max} and Vp_{max} are the maximum values of Nc and Vp for the examined period. For α and β factors, it is applied $\alpha + \beta = 1$ and $\alpha, \beta > 0$. The factors α and β are the values which give the best cross correlation coefficient values between P_i-index and CR intensity. This index shows no time-lag with CR intensity as the sunspot number does as a result of the hysteresis effect [6]. Especially the correlation coefficient from linear fitting between CR intensity and P_i-index from Eq. (1) are highly anticorrelated with a correlation coefficient r=0.84.

In the present work the P_i-index was considered to be associated with each event/CME taking in to account the angular width of the event and the linear speed according to the relation:

$$P_i = \frac{width}{360^\circ} + \frac{Vp}{Vp_{max}} \tag{2}$$

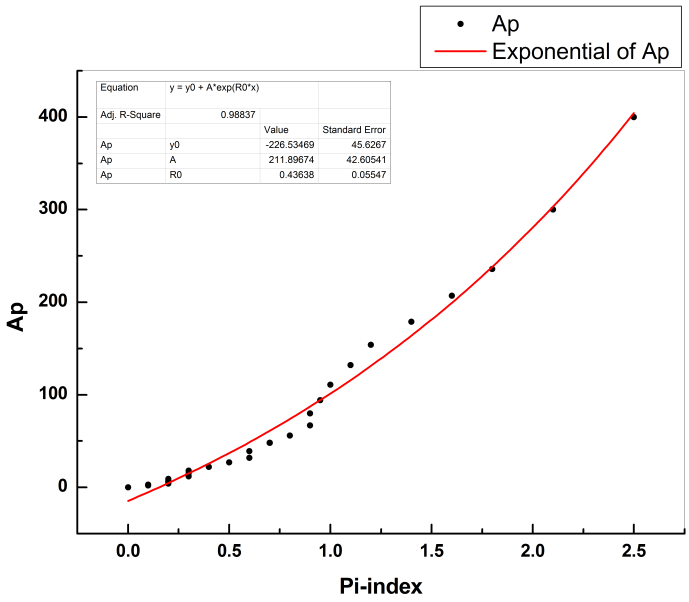

Figure 1: The geomagnetic Ap values and the P_i-index values respectively for events with different characteristics. Events with quiet and active conditions were used in order to find the relation between Ap and P_i indexes. The best fit was an exponential model (red line).

where the term 360 degrees is valid for HALO CMEs and Vp_{max} is the maximum linear speed which has been selected for normalization purposes. Especially for the period 1996-2013 the Vp_{max} was defined as 1700 Km/s in order to give the maximum value of P_i-index for an event which is 2.5. For a case study event of October 2003 the P_i-index value was 2.45 for the event of October 28, 2003 at 11:30 U.T., as the CME was a HALO one and the linear speed was 2459 Km/s. This CME was connected with a X17.2 solar flare. This event produced a strong geomagnetic storm at October 29, 2003 with a daily Ap value equal to 190 and a minimum Dst value equal to -350 nT. The same calculations of Pi-index values have been made for each event separately. 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:

$$Ap = Ap_0 + Ae^{R_0 P_i} \tag{3}$$

where Ap is the calculating value of Ap index which is the dependent variable, Ap_0, A and R_0 are the constants -226.5, 211.9 and 0.43638 respectively and P_i is the P_i-index value which is the independent variable (Fig. 1).

For the previous case study of the CME of October 28, 2003 at 11:30 U.T., the P_i-index was found to be 2.45 and the estimated Ap index value from the Eq. (3) was 390. This is in a very good approximation with only a 3% difference from the observed value of maximum Ap being 400 at the 18:00-24:00 U.T. of October 30, 2003 during this strong G5 geomagnetic storm.

4 Conclusions

The main findings of this study are summarized as follows:

- A first attempt to be developed a new model which could estimate the values of geomagnetic index Ap through the P_i-index is presented in this work.
- The first results from the data analysis revealed on 20 events which were connected with CMEs and finally produced geomagnetic storms with Ap daily value greater than 100. Furthermore 10 of those events were connected also with X-class solar flares and 6 events with M-class solar flares.

- The new formation of P_i-index based on the angular width and the linear speed of the CME associates this index with each one event/CME, when in previous works each value of this index was a monthly value, this makes the P_i-index almost a real-time variable useful for space weather applications.
- The values of the Ap index as there are calculated from the exponential Eq. (3) are in accordance with the observed values. Especially the half calculated Ap values were very close to the observed values with divergence less than 10%. The other cases have divergence from 10% to 40% but only three events had divergence greater of 50%.
- Especially for the case study of the CME/event of October 28, 2003 at 11:30 U.T. the P_i-index was 2.45 and the estimation of Ap maximum value from the exponential model of Eq. (3) was 390 when the observed value was 400 at 18:00-24:00 U.T. of October 30, 2003 during the geomagnetic storm.
- The proposed method will be useful for Space Weather studies and it will be applied to the Athens Space Weather Forecasting Center very soon. Moreover this preliminary study will be extended for events with geomagnetic storms with daily Ap value less than 100. A new research is almost ready where the magnetic field of the CME is taking into account also for the formation of the CME-index.

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