International Journal of Engineering and Applied Physics (IJEAP)
Vol. 6, No. 1, January
ISSN: 2737-8071

Correlation among ap, Dst and AE Indices for Solar Cycle 23 and 24

Debojyoti Halder[1] and Bipasa Raha[2,*]
[1]Department of Physics, R. B. C. Evening College, Naihati 743165, West Bengal, India
Email: debojyoti829@gmail.com
[2]Department of Physics, D. S. College, Katihar 854105, Bihar, India
Email: bipasa.raha@gmail.com
*Corresponding author

Article Info

Article history
Received Jun 9, 2025
Revised Aug 11, 2025
Accepted Feb 1, 2026

Keywords
Geomagnetic Index
ap index
AE index
Dst index
Solar cycle 23
Solar cycle 24

ABSTRACT

Daily average values of the ap, Dst and AE geomagnetic activity indices have been studied for the fifty most geomagnetically active days in Solar cycle 23 and 24. This study shows that, (1) the average values of ap, Dst and AE indices for Solar Cycle 23 are much greater than that of cycle 24 which is evidently shown by the linear variations of the plots. (2) The correlation coefficient of ap x -Dst is much higher than AE x -Dst but both are much lower than that of ap x AE for solar cycle 23 but for solar cycle 24, the correlation coefficient of ap x -Dst is almost similar to ap x AE. (3) When the correlation is done for both the solar cycles, the result stays the same. The results show that, solar cycle 23 was geomagnetically much more active than solar cycle 24.

This is an open access article under the CC BY license.

Corresponding Author
Dr. Bipasa Raha
Assistant Professor
Department of Physics,
S. College, Katihar, Bihar
Email: bipasa.raha@gmail.com

1. INTRODUCTION

In the study of solar-terrestrial relationships, the use of indices of geomagnetic activity plays an important role. The four most commonly used indices are AE, Dst, Kp and the linear counterpart of the latter, ap. Available since 1932, the Kp index represents the intensity of planetary magnetic activity as seen at sub-auroral latitudes and is given for each 3-h interval. The individual K indices for each of the contributing mid-latitude observatories reflect the maximum range of any component of the field over the 3-h interval at each station. The Kp index is the average of the K values from all contributing observatories. A conversion scale transforms the quasi-logarithmic Kp to a linear index named ap. AE was defined in 1966 by Davis and Sugiura so that it measures primarily the variations in the auroral electrojets [1]. It is based on 1-min values of the H-component trace from auroral-zone observatories located around the world. The data of these observatories are plotted as a function of universal time. The upper and lower envelopes are defined as AU and AL indices, respectively, and are believed to represent the maximum eastward and westward electrojet currents. The sum of the absolute values of AL and AU is called AE. Introduced in 1964, the ring-current index Dst measures primarily the ring-current magnetic field. It is based on hourly averages of the H-component recorded at four low-latitude observatories, subtracting the average square and the permanent field from the disturbed magnetic field. A detailed description of the methods by which these indices are derived and the correspondent uncertainties can be found in [2]. Although these three indices have been calculated for many years, only a few studies on their interrelationships have been published [3-5]. The purpose of this study is to understand better the possible relationships between them. Further, this study was done for two solar cycles.

2. METHODS OF DATA ANALYSIS

Pearson correlation method has been used to estimate a physical relationship between two different geomagnetic indices quantitatively by calculating the linear correlation coefficient *r*. This correlation coefficient determines the relationship of the two indices. Again, to estimate the correlation between one index and two others, a multiple correlation coefficient was calculated. This coefficient serves as a useful tool to test whether one particular index can be expressed in terms of other two or vice versa.

The formula for the Pearson product moment correlation coefficient, *r*, is,

$$r = \frac{\sum(x - \bar{x})\,(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2}\sum(y - \bar{y})^2}$$

where x and y are the sample means AVERAGE (array1) and AVERAGE (array2).

We used the following expressions for these two methods, as described by P. R. Bevington [6]. The linear adjust is given by,

$$y = a + \sum_{j=1}^{n} b_j x_j$$

Here, *y* and x_j, *j* = 1; 2 (*n* = 2), represent the different geomagnetic indices chosen for multiple correlation, and *a* and b_j are the coefficients obtained from the best fit.

The sample covariance s_{jk}^2 is,

$$s_{jk}^2 \equiv \frac{\frac{1}{N-1}\sum_{i=1}^{N}[\frac{1}{\sigma_i^2}(x_{ij} - \bar{x_j})(x_{ik} - \bar{x_k})]}{\frac{1}{N}\sum_{i=1}^{N}\frac{1}{\sigma_i^2}}$$

where j; k = 1; 2; σ_i is the standard deviation, *N* is the number of data points and $\bar{x_j}$ is,

$$\bar{x_j} \equiv \frac{\sum_{i=1}^{N}\frac{x_{ij}}{\sigma_i^2}}{\frac{1}{N}\sum_{i=1}^{N}\frac{1}{\sigma_1^2}}$$

The sample variance is given by,

$$s_j^2 \equiv s_{jj}^2$$

The linear-correlation coefficient can be expressed in terms of,

$$r_{jk} \equiv \frac{s_{jk}^2}{s_j s_k}$$

In analogy with this definition of the linear-correlation coefficient, we define the multiple-correlation coefficient *r* to be,

$$r^2 \equiv \sum_{j=1}^{N}\left\{b_j\left(s_{jy}^2/s_y^2\right)\right\} = \sum_{j=1}^{N}\left[b_j\left\{\left(s_j/s_y\right)r_{jy}\right\}\right]$$

3. DATA USED

This study was done taking into account the most geomagnetically active fifty days of solar cycle 23 and 24. These dates and the values of ap, Dst, and AE indices on those dates are gives in tabular form in Table 1 for solar cycle 23 and 24. Solar cycle 23 started from August 1996 and ended on December 2008 while solar cycle 24 started from December 2008 and ended on December 2019 [7-9]. For convenience, in this work, we have used ap instead of Kp, since ap is based on a linear scale, whereas Kp is on a quasi-logarithmic scale. Since Dst and AE indices have average hourly values, ap was averaged for the same interval for the purpose of comparison. This implies that the results of this study have a resolution limited to an hourly interval and therefore higher-resolution phenomena like substorms could not be studied. Figure 1 shows daily mean hourly values of ap, Dst, and AE for the 50 chosen dates for solar cycle 23 and Figure 2 shows the same for solar cycle 24. Some correlation (or anticorrelation) between them is easily seen from the plots.

Table 1. Most geomagnetically active Dates of solar cycle 23 and 24

Most active Dates of solar cycle 23	ap (nT)	Dst (nT)	AE (nT)	Most active Dates of solar cycle 24	ap (nT)	Dst (nT)	AE (nT)
04-05-1998	101	-205	597	01-03-2011	27	-88	431
27-08-1998	144	-155	950	05-08-2011	42	-96	312
25-09-1998	117	-207	762	06-08-2011	31	-115	341
08-11-1998	66	-149	493	26-09-2011	38	-118	394
22-09-1999	50	-173	305	27-09-2011	30	-102	354
23-09-1999	28	-155	130	25-10-2011	38	-147	294
22-10-1999	91	-237	506	07-03-2012	48	-88	547
06-04-2000	82	-291	434	09-03-2012	87	-145	711
07-04-2000	74	-292	298	23-04-2012	26	-106	417
24-05-2000	93	-147	561	24-04-2012	41	-120	490
15-07-2000	164	-289	1000	15-07-2012	78	-139	912
16-07-2000	50	-300	243	16-07-2012	42	-113	744
12-08-2000	123	-234	728	01-10-2012	32	-122	271
17-09-2000	56	-201	391	08-10-2012	40	-99	527
18-09-2000	70	-193	269	09-10-2012	46	-109	473
05-10-2000	116	-181	646	13-10-2012	47	-90	612
06-11-2000	55	-159	571	14-11-2012	37	-108	391
07-11-2000	46	-151	455	17-03-2013	72	-132	684
20-03-2001	74	-149	711	18-03-2013	7	-96	46
31-03-2001	192	-387	699	01-06-2013	58	-124	546
01-04-2001	38	-228	363	28-06-2013	22	-91	600
11-04-2001	85	-271	631	29-06-2013	50	-102	627
12-04-2001	50	-236	352	19-02-2014	43	-119	443
01-10-2001	48	-148	615	20-02-2014	37	-95	468
03-10-2001	69	-166	694	27-02-2014	20	-97	304
21-10-2001	57	-187	396	28-02-2014	11	-94	146
22-10-2001	96	-177	561	07-01-2015	31	-107	276
23-10-2001	17	-165	165	17-03-2015	108	-234	633
28-10-2001	44	-157	485	18-03-2015	47	-200	488
06-11-2001	142	-292	823	19-03-2015	26	-99	410
07-11-2001	19	-165	206	22-06-2015	57	-114	560
24-11-2001	104	-221	600	23-06-2015	72	-198	555
20-04-2002	70	-149	692	16-08-2015	32	-98	562
07-09-2002	57	-177	655	27-08-2015	52	-103	761
08-09-2002	36	-181	271	28-08-2015	40	-102	638
01-10-2002	67	-176	550	09-09-2015	59	-105	819
02-10-2002	53	-160	466	07-10-2015	74	-130	697
18-08-2003	108	-148	842	08-10-2015	45	-97	646
29-10-2003	204	-350	1091	20-12-2015	70	-166	726
30-10-2003	191	-383	870	21-12-2015	38	-159	331
31-10-2003	116	-307	449	31-12-2015	35	-105	521
20-11-2003	150	-422	829	01-01-2016	30	-116	374
21-11-2003	42	-309	293	20-01-2016	26	-101	423
27-07-2004	186	-170	1111	06-03-2016	31	-99	290
08-11-2004	140	-374	878	08-05-2016	70	-95	829
09-11-2004	119	-214	983	13-10-2016	46	-110	610
10-11-2004	161	-263	921	14-10-2016	22	-102	361
15-05-2005	87	-247	571	28-05-2017	49	-125	617
24-08-2005	102	-184	746	08-09-2017	106	-122	677
15-12-2006	94	-162	826	26-08-2018	67	-175	212

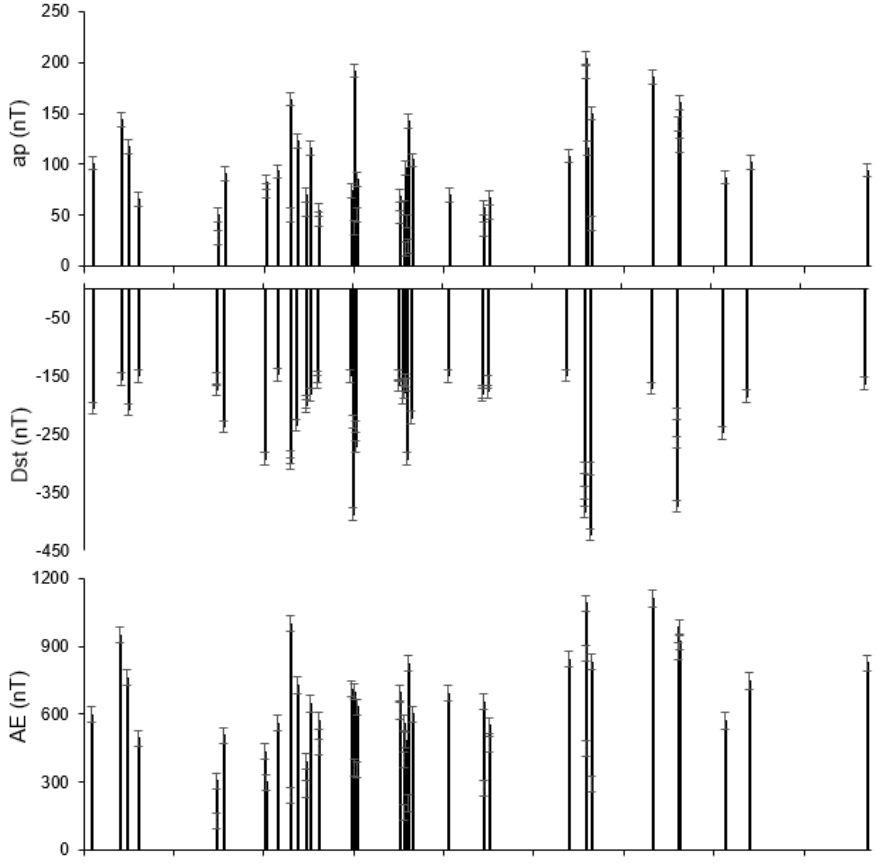

Figure 1. Plots of ap, Dst and AE indices in nT for the above-mentioned dates, for solar cycle 23

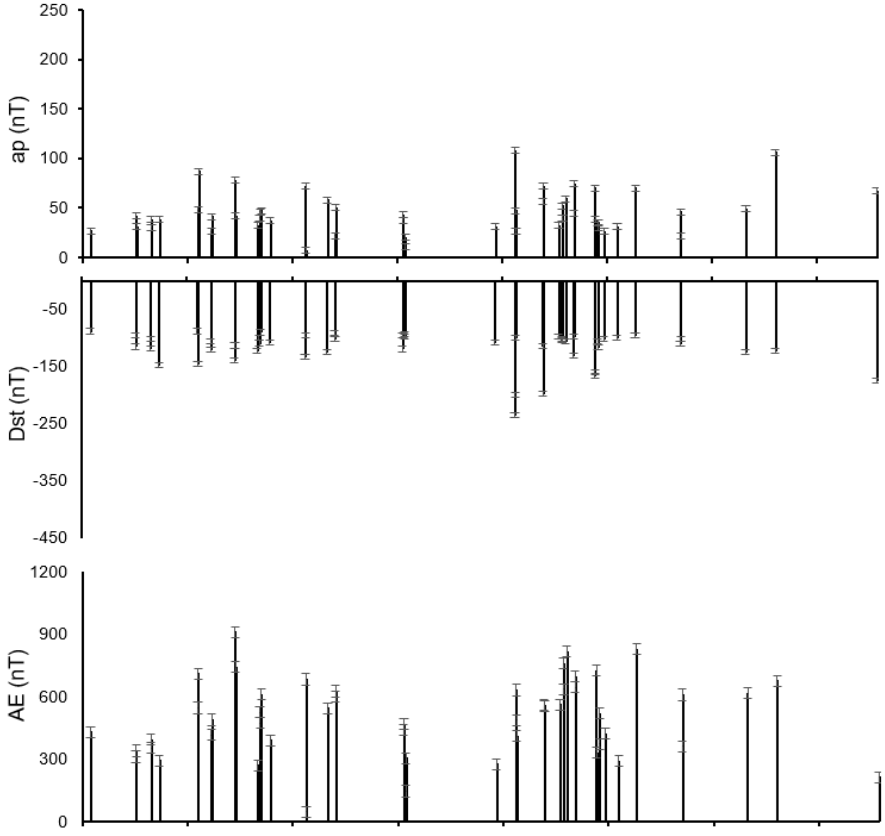

Figure 2. Plots of ap, Dst and AE indices in nT for the above-mentioned dates, for solar cycle 24

4. RESULTS

4.1 Comparison of the geomagnetic indices ap, Dst and AE for solar cycle 23 and 24

Here we have done a graphical comparison of the geomagnetic indices under consideration.

In Figure 3, we have plotted the values of ap indices for the 50 active dates given in Table 1 of solar cycle 23 and 24. In Figure 4 and Figure 5, same bar diagram plots are given for Dst and AE indices respectively. It is clearly seen from these 3 plots that, the solar activity on those active dates of solar cycle 23 were much higher than cycle 24.

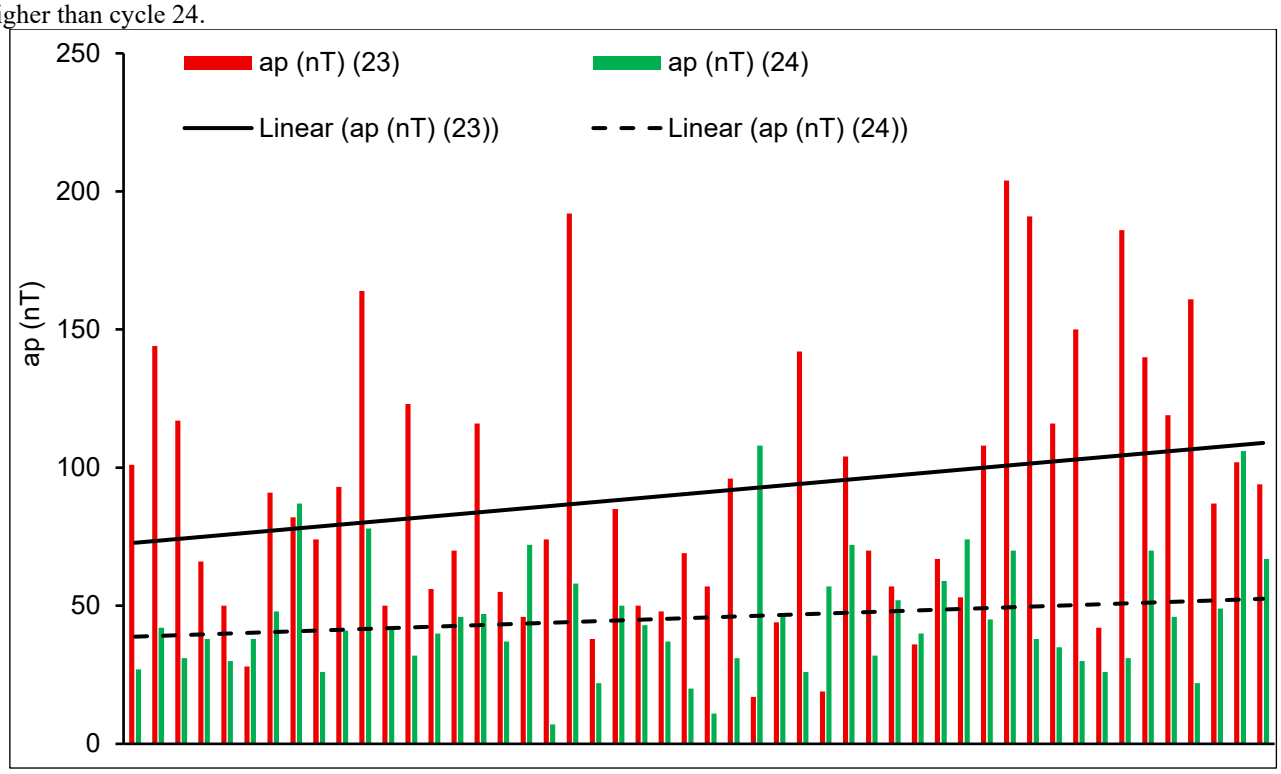

Figure 3. Comparison of ap index for both the solar cycles with linear trendlines

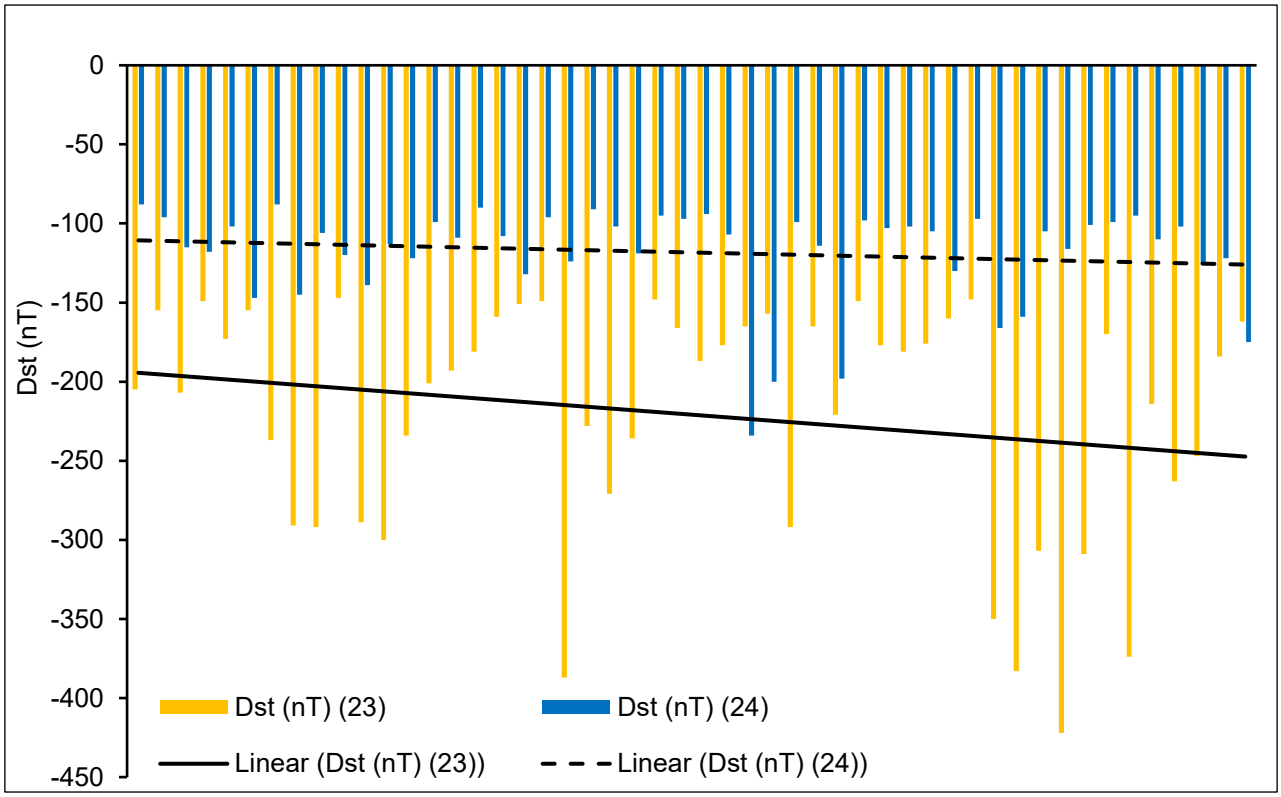

Figure 4. Comparison of Dst index for both the solar cycles with linear trendlines

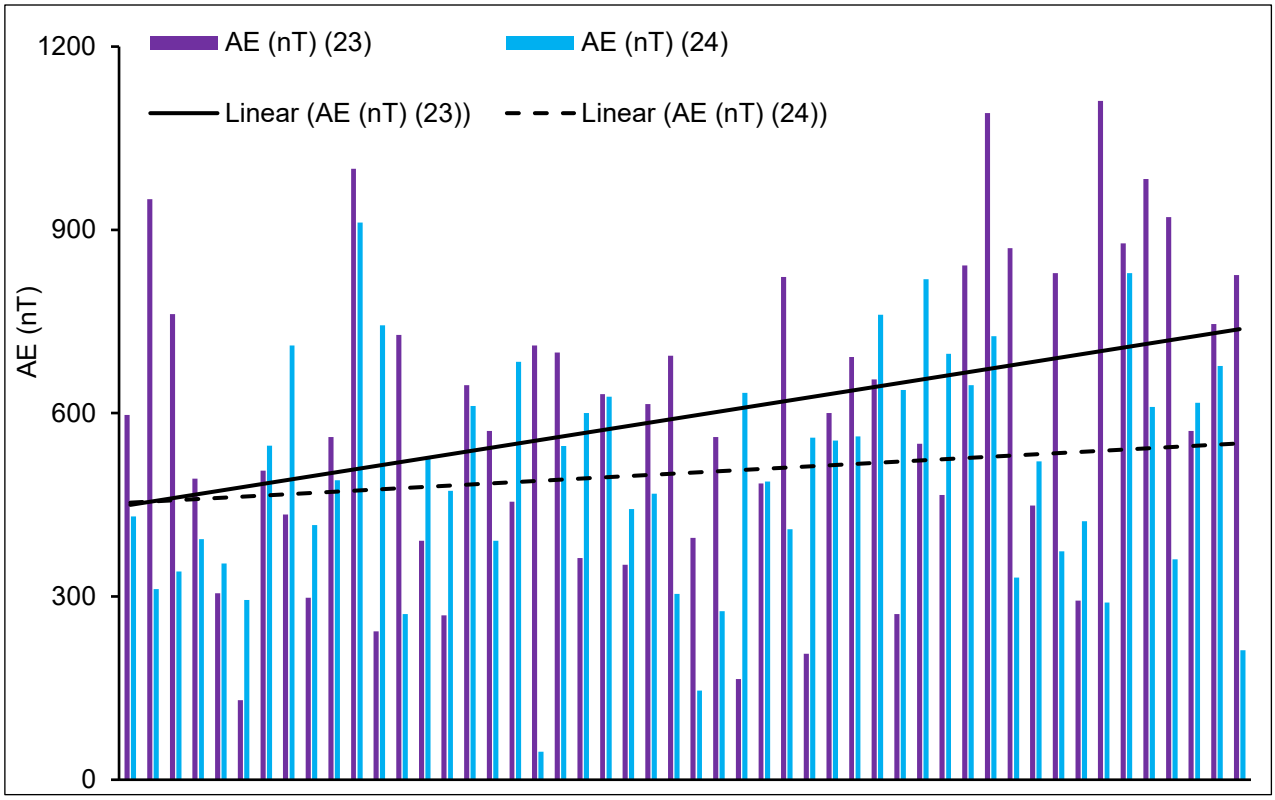

Figure 5. Comparison of AE index for both the solar cycles with linear trendlines

4.2 Correlation of the three geomagnetic indices for solar cycle 23 and 24

Here we have done the correlation between ap x (-Dst), ap x AE and AE x (-Dst) and among the three indices (ap x AE x (-Dst)). For solar cycle 23, the correlation coefficients are given in Table 2 and Figure 6 represents the graphical representation (bar diagram) of the correlation coefficients. For solar cycle 24, the correlation coefficients are given in Table 3 and Figure 7 represents the graphical representation (bar diagram) of the correlation coefficients. The correlation of the indices for both the cycles Figure 8 represents the graphical representation (bar diagram) of the correlation coefficients.

Table 2. Correlation coefficients of the geomagnetic indices for solar cycle 23

ap x -Dst	ap x AE	AE x -Dst	ap x AE x -Dst
1	1	1	1
0.57	0.83	0.23	0.837929317
			0.572201427

Table 3. Correlation coefficients of the geomagnetic indices for solar cycle 24

ap x -Dst	ap x AE	AE x -Dst	ap x AE x -Dst
100%	100%	100%	100%
59.80%	66.17%	11.60%	66.17%
			11.60%

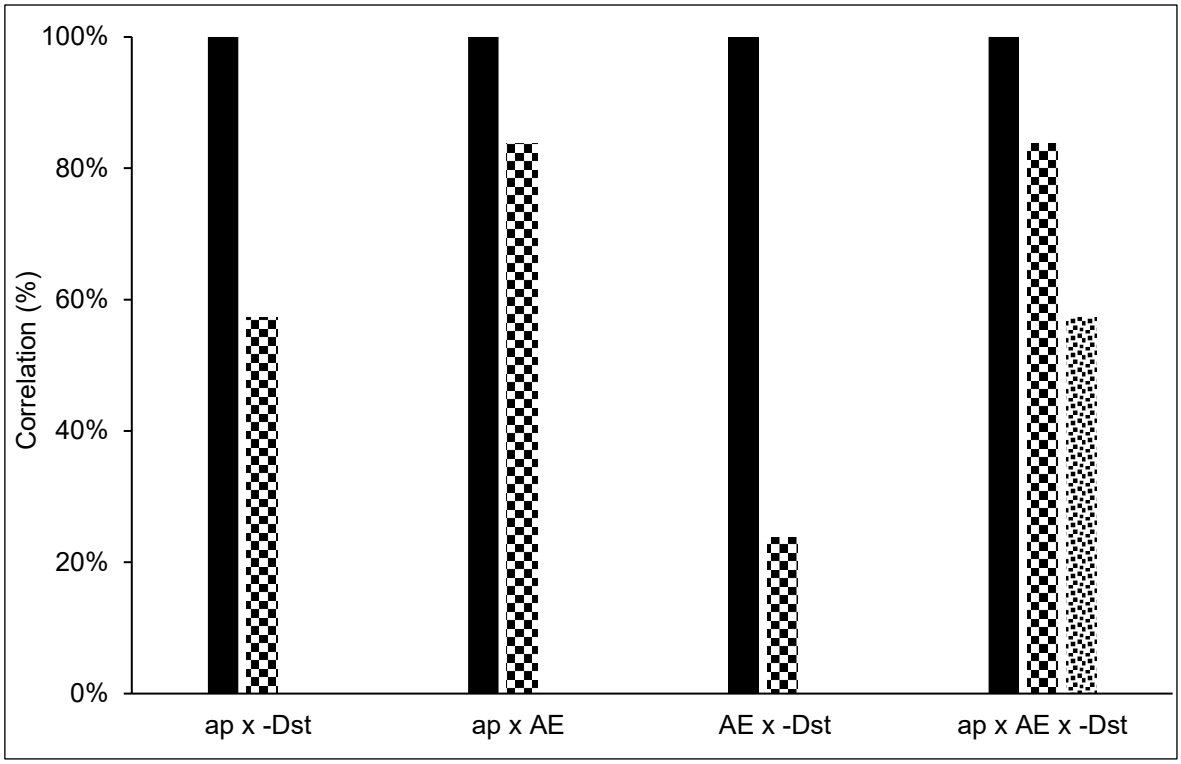

Figure 6. Correlation % of ap x -Dst, ap x AE, AE x -Dst and ap x AE x Dst for solar cycle 23

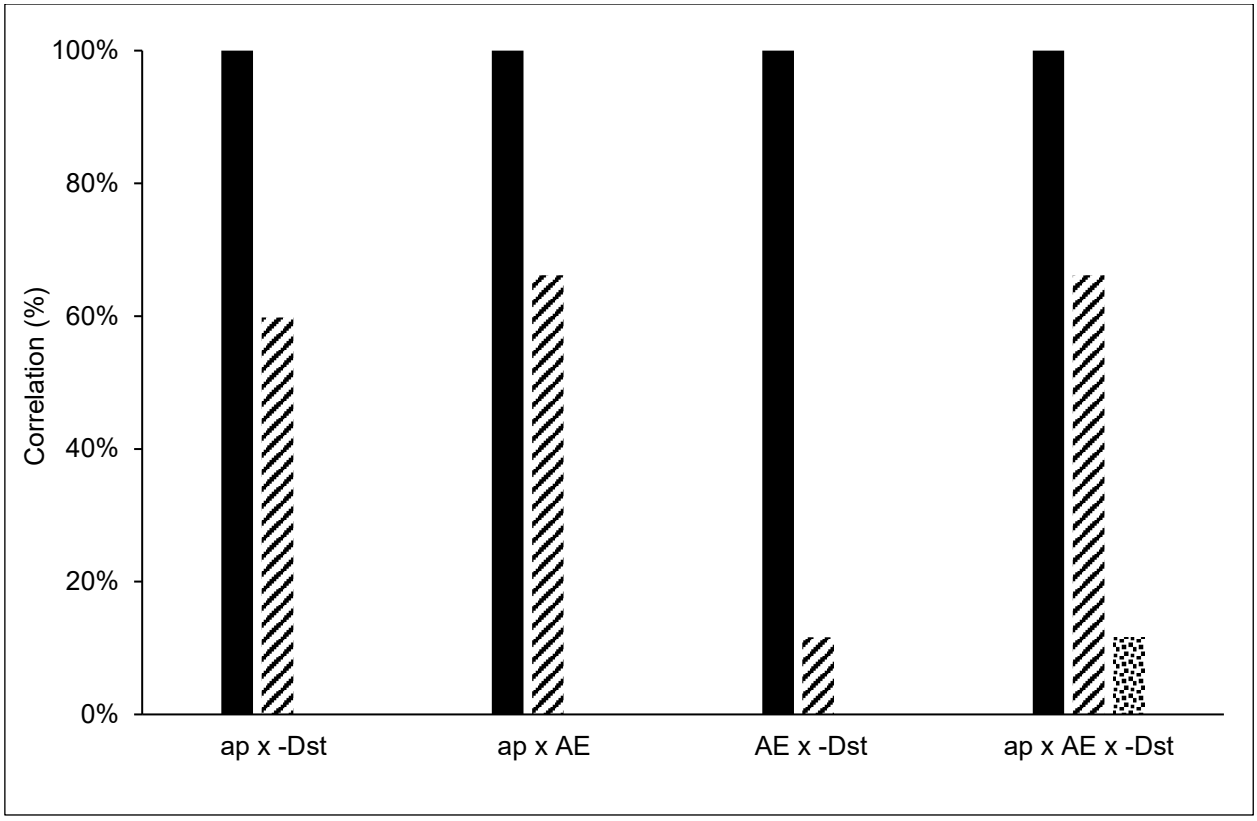

Figure 7. Correlation % of ap x -Dst, ap x AE, AE x -Dst and ap x AE x Dst for solar cycle 24

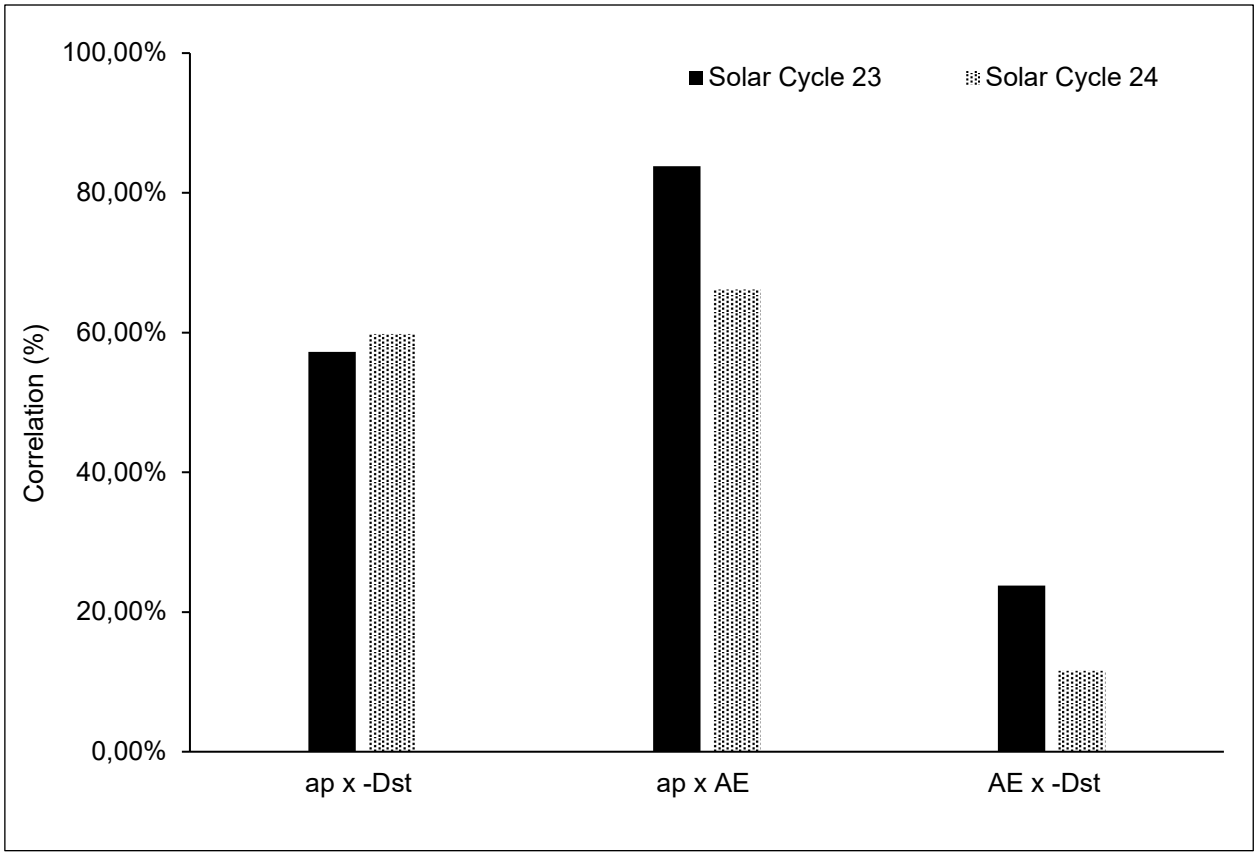

Figure 8. Correlation % of ap x -Dst, ap x AE and AE x -Dst for both the solar cycle

5. CONCLUSIONS

In this work, we have made an effort to achieve a better understanding of the geomagnetic indices and their relationships during the dates of top fifty geomagnetic storms for both the solar cycle 23 and 24 by means of their comparisons and correlations. The main conclusions can be summarized as follows. The variation of ap index and Dst index are definitely much higher for the chosen dates of solar cycle 23 than of cycle 24. The occurrence of several geomagnetic storms gives a higher Dst value [10, 11]. The average of AE observed for those dates in solar cycle 23 is slightly greater than the average for solar cycle 24, but the variation is less than the other two indices. The higher occurrence of substorms is responsible for a higher AE in cycle 23. The variation associated with an enhancement in geomagnetic activity at the equinoxes was found to be highest for Dst. However, it can be also seen in the ap distribution, but hardly noticed in AE. The correlation coefficient of ap x AE (hourly values averaged for a day, r = 83.79%) for solar cycle 23 is the highest of all, which is 16.5% higher than the same correlation for cycle 24. No lag was found when correlating AE with ap, as both indices mainly monitor ionospheric electrojets [12-14]. For ap x -Dst correlation, it is surprising to find that the correlation coefficient r is slightly (~2.5%) higher for solar cycle 24 (r = 59.80%). Between AE and the -Dst indices, the correlation coefficient is much lower for both the cycles than the other two correlation coefficients, for solar cycle 23 r being 23.79% and for solar cycle 24, 11.60% which have the lowest value of them all. It was found that a better correlation can be achieved when all three indices are correlating and that Dst index has a much greater influence on ap during periods of geomagnetic storms. We believe that, these relationships may be useful when one index is calculated from the other known indices.

ACKNOWLEDGEMENTS

The AE, Dst and ap data used in this study were obtained from World Data Center for Geomagnetism, Kyoto. The data used in this study were obtained from WDC for Geomagnetism, Kyoto (https://wdc.kugi.kyoto-u.ac.jp/)

REFERENCES

[1] P. N. Mayaud, Derivation, meaning and use of geomagnetic indices, AGU monograph, (Washington DC), 1980.
[2] W. B. Cade III, et al., "A correlative comparison of the ring current and auroral electrojects using geomagnetic indices," *Journal of Geophysical Research,* vol. 100, pp. 97-105, 1995.
[3] W. H. Campbell, "Occurrence of AE and Dst geomagnetic index levels and the selection of the quietest days in a year," *Journal of Geophysical Research,* vol. 84, pp. 875-881, 1979.

[4] G. Rostoker, "Geomagnetic indices," *Reviews of Geophysics and Space Physics,* vol. 10, pp. 935-950, 1972.
[5] P. R. Bevington, Data reduction and error analysis for the physical sciences, McGraw-Hill, (New York), 1969.
[6] T. N. Davis, M. Sugiura, "Auroral electrojet activity index AE and its universal time variations," *Journal of Geophysical Research*, vol. 71, pp. 785-801, 1966.
[7] B.O. Adebesin, "Investigation into the linear relationship between the AE, Dst and ap indices during different magnetic and solar activity conditions," *Acta Geodaetica et Geophysica*, vol. 51, 315–331, 2016.
[8] O.O. Alabi, et al., "Comparative Analysis Into The Geomagnetic Indices (Ap, Ae, Dst, Bz) During Disturbed Period And Quiet Conditions Of Solar Maximum Year (2001)," *International Journal of Innovation And Scientific Research*, vol. 17, pp. 155–163, 2015.
[9] T.L. Gulyaeva, "Correspondence of variations of AE and Apo indices in 23–24 solar cycles, *Geomagnetism and Aeronomy,* vol. 64, pp. 433-440, 2024.
[10] G. Verbanac, et al., "Solar wind high-speed streams and related geomagnetic activity in the declining phase of solar cycle 23," *Astronomy and Astrophysics*, vol. 533, A49, 2011, doi: https://doi.org/10.1051/0004-6361/201116615
[11] W. B. Cade III, et al., "A correlative comparison of the ring current and auroral electrojets using geomagnetic indices, *Journal of Geophysical Research*, vol. 100(A1), pp. 97–105, 1995, doi:10.1029/94JA02347.
[12] B. O. Adebesin, V. U. Chukwuma, "On the variation between Dst and IMF Bz during 'intense' and 'very intense' geomagnetic storms, *Acta Geodaetica et Geophysica,* vol. 43(1), pp. 1–15, 2008, doi:10.1556/AGeod.43.2008.1.1.
[13] S. Rochel Grimald, "A comparative study of Kp, Ap, Km, Am, Dst and AE index", Art. no. EGU2013-5316, 2013, *EGU General Assembly* , held 7-12 April, 2013 in Vienna, Austria, id. EGU2013-5316, 2013.
[14] A. M. El-Taher, A. A. Thabet, "The interconnection and phase asynchrony between the geomagnetic indices' periodicities: A study based on the interplanetary magnetic field polarities 1967–2018 utilizing a cross wavelet analysis," *Advances in Space Research*, vol. 67, pp. 3213-3227, 2021.