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EVALUATION OF SUNSPOT POTENTIAL IN RELATION TO SUNSPOT NUMBER AND SPECIFIC GEOMAGNETIC PARAMETERS

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ABSTRACT

It is known that sunspot cycle as solar that is about 11 years change from the sun's activity. Also the period of solar cycle, the number and size of sunspot and coronal loops all exhibits a synchronized fluctuation. The flip occurred if the solar cycle is near its maximum due to the magnetic field from the sun. There are regions of reduced surface temperature due to the concentration of magnetic flux that inhibit convection. Also the group of sunspot would last from a few days to a few months. The goal of this work is obtain to the correlation of geomagnetic Ap-index CRz-Ap and CRz-Dst. The method used is the Zurich number for the sunspot. The Sunspot Area (SSA), International Sunspot Number (ISSN), Solar X-ray peak flux, Maximum Coronal Mass Ejection Speed index (MCMESI), geomagnetic Ap and Dst index were used. The result obtained is the Sunspot Potential. Geomagnetic Ap and Dst index were Observed. The Geomagnetic CRz-Ap and CRz-Dst index are achieved.

Keywords: *Sunspot, SSA, ISSN, Geomagnetic, Sunspot Number and Zurich Number.*

INTRODUCTION

The solar cycle, also known as solar magnetic activity cycle, sunspot cycle or Schwabe cycle, is a nearly periodic 11-year change in the sun's activity measured in terms of radiation in the number of observed sunspots on the sun's surface (Vaquero *et al*, 2009). Over the period of a solar cycle, levels of solar radiation and ejection of solar material, the number and size of sunspot, solar flares and coronal loops all exhibits a synchronized fluctuation from a period of minimum activity to a period of maximum activity back to a period of minimum activity (Soon, *et al*,2003).

The magnetic field of the sun flips during its solar cycle, with the flip occurring when the solar cycle is near its maximum. After two solar cycles, the sun's magnetic fields return to its original state, completing what is known as a Hale cycle (Love, 2013). This cycle has been observed for centuries by changes in the sun's appearance and by terrestrial phenomena such as aurora but was not clearly identified until 1843. Solar activity, driven by both the solar cycle and transient aperiodic processes, governs the environment of inter-planetary space by creating space weather and impacting space – and ground-based technologies as well as the earth's atmosphere and also possibly climate fluctuations on scales of centuries and longer (Solanki *et al*, 2004). Understanding and predicting the solar cycle remains one of the grand challenges in astrophysics with major ramifications for space science and the understanding of magneto hydrodynamic phenomena elsewhere in the universe.

Sunspots are phenomena on the sun's photosphere that appear as temporary spots that are darker than the surrounding areas (Hudson, 2008). They are regions of reduced surface temperature caused by concentration of magnetic flux that inhibit convection. Sunspot appears within active regions, usually in pairs of opposite magnetic polarity (Weart, 2006). Their number varies according to the approximately 11-year solar cycle. Individual sunspot or groups of sunspots may last anywhere from a few days to a few months, but eventually decay. Sunspots expand and contract as they move across the surface of the sun, with diameter ranging from 16km (10mi) to 160, 000km (100, 000mi). Lager sunspot can be visible from earth without the aid of a telescope. They may travel at relative speed, or proper motions, of a few hundred meters per second when they first emerge (Owens, 2017). Indicating intense magnetic activity, sunspot accompany other active region phenomena such as coronal loops, prominences and reconnection events. Most solar flares and coronal mass ejections originate in these magnetically active regions around visible sunspot grouping (Wilson *et al*, 2021). Similar phenomena indirectly observed on stars other than the sun are commonly called star spots, and both light and dark spots have been measured.

There are numerous indices of magnetic activity. The International Association of Geomagnetism and Aeronomy (IAGA) officially recognize magnetic indices as, Am, Kp, Dst and AE (Felipe *et al*, 2016). More information about the IAGA indices is available from the International Services for Geomagnetic Indices (ISGI). The K-index is quasi-logarithmic local index of the 3-hourly range in magnetic activity relative to an assumed quiet-day curve for a single geomagnetic observatory site.

First introduced by J. Bartels in 1938, it consists of single-digit 0 through 9 for each 3-hour interval of the universal time day (UT) (Schlichenmaier, *et al*, 2010). The planetary 3-hour range index Kp is the mean standardized K-index from 13 geomagnetic observatories between 44 degrees and 60 degrees Northern or Southern geomagnetic latitude. The scale is 0 to 9 expressed in terms of a unit, eg. 5– is $4\frac{2}{3}$, 5 is 5 and 5+ is $5\frac{1}{3}$ (Solanki, 2003).

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Indicating intense magnetic activity, sunspots accompany other active region phenomena such as coronal loops, prominences, and reconnection events. Most solar flares and coronal mass ejections originate in these magnetically active regions around visible sunspot groupings (Schlichenmaier et al., 2010). Similar phenomena indirectly observed on stars other than the Sun are commonly called starspots, and both light and dark spots have been measured.

MATERIALS AND METHOD

The daily total number of sunspots (Zurich number or relative number) is calculated by:

$$Rz = k(10g + f) \qquad 1$$

Where k is correction of factors, g if the number of group, and is the total number individual sunspot in all group.

In this study, sunspot area (SSA), international sunspot number (ISSN), solar X-ray peak flux, Maximum Coronal Mass Ejection Speed

Index (MCMESI), geomagnetic Ap index, and geomagnetic Dst index datasets were used. Solar X-ray peak flux data are taken from the National Oceanographic and Atmospheric Administration (NOAA) Space Weather Prediction Center (SWPC) for the time period from august 2002 through December 2022 ISSN data are taken from World Data Center-Sunspot Index and Long-term Solar Observation (WDC-SILSO SIDC), SSA data are taken from the Marshall Space Flight Center (MSFC), geomagnetic Ap and Dst indices are taken from the National Oceanographic and Atmospheric Administration (NOAA) and CME data are taken from the National Aeronautics and Space Administration websites, First, to recalculated the FPP previously introduced based on the peak flux of X-ray solar flares indeed of X-ray solar flare numbers. For this purpose, we have used only C, M, and X class flares from 2002 to 2022. To calculate the flare production potential, the M class there's peak fluxes were used as a reference and C and X classes were concerned to M class by dividing or multiplying by 10, respectively.

$$\text{FPP of a Zurich class} = \frac{total\ x{-}ray\ fleak\ peak\ flix\ of\ sunpot\ clss}{total\ number\ of\ sunspoty\ group\ f\ the\ same\ class}$$

2

Using FPPs formula was modified as

$$\text{CRz} = 2\sum_{i=1}^{n}\left((P_i \times g_i) + f_i\right)$$

3

Where CRz describes the calculated daily total sunspot number, Pi is the FPP of theits class sunspot group gi is the number of sunspot group of the ith class, and fi is the total number of individual sunspot in all groups of the ith class. According to this equation, each sunspot group contributes as the daily total number depending on its FPP.

RESULTS AND DISCUSSION

Results

Table 1 Cross-Correlation results for Geomagnetic AP index

S/N	Lag	CRz-AB	ISSN-Ap
1	-950	0.00	0.00
2	-900	0.01	0.01
3	-850	-0.01	-0.01
4	-800	0.02	0.02
5	-750	-0.05	-0.05
6	-700	0.01	0.01
7	-650	-0.08	-0.08
8	-600	0.04	0.04
9	-550	-0.09	-0.09
10	-500	0.11	0.13
11	-450	-0.1	-0.13
12	-400	0.13	0.12
13	-350	-0.15	-0.17
14	-300	0.15	0.07
15	-250	-0.17	-0.18
16	-200	0.2	0.22
17	-150	-0.18	-0.20
18	0.00	0.29	0.39
19	50	-0.25	-0.25
20	100	0.19	0.19
21	150	-0.17	-0.16
22	200	0.11	0.13
23	250	-0.18	-0.19
24	300	0.18	0.17
25	400	-0.15	-0.16
26	500	0.18	0.17
27	550	-0.17	-0.16
28	600	0.03	0.04
29	700	-0.09	-0.08
30	800	0.03	0.03
31	900	-0.05	-0.05
32	950	0.00	0.00

Table 2: Cross Correlation Result for Geomagnetic Dst index

S/N	Lag	CRz-Dst	ISSN Dst
1	-800	0.00	0.00
2	-750	0.01	0.01
3	-700	0.00	0.00
4	-670	0.03	0.03
5	-630	-0.02	-0.02
6	-600	0.04	0.04
7	-500	0.01	0.01
8	-500	0.05	0.07
9	-450	-0.11	-0.13
10	-400	0.10	0.11
11	-350	-0.15	-0.17
12	-300	0.18	0.19
13	-250	-0.11	-0.12
14	-200	0.24	0.29
15	-150	-0.18	-0.19
16	-100	0.18	0.19
17	0.00	-0.4	-0.38
18	100	0.22	0.21
19	150	-0.14	-0.13
20	200	0.14	0.14
21	250	-0.12	-0.11
22	300	0.12	0.12
23	350	-0.14	-0.14
24	400	0.04	0.04
25	450	-0.1	-0.09
26	500	0.07	0.06
27	550	0.02	0.02
28	600	0.04	0.03
29	700	0.02	0.02
30	750	0.03	0.03
31	800	0.00	0.00

Table 3: Cross-correlation results for MCMESI

S/N	Lag	CRz-MCMESI	ISSN-MCMESI
1	-275	0.00	0
2	-250	0.02	0.01
3	-200	-0.1	-0.10
4	-150	0.2	0.21
5	-75	-0.55	-0.56
6	0.00	0.79	0.78
7	75	-0.42	-0.41
8	150	0.20	0.21
9	200	-0.10	-0.10
10	250	0.02	0.02
11	275	0.00	0.00

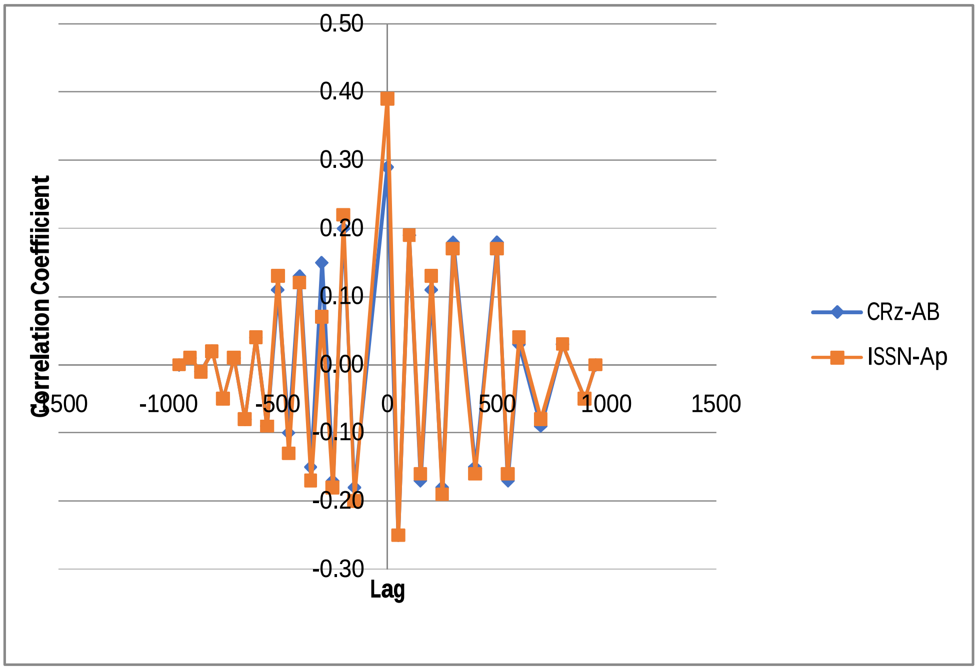

Figure 1:Lag against Correlation of Geomagnetic Ap-indexCRz-AB and ISSN-Ap

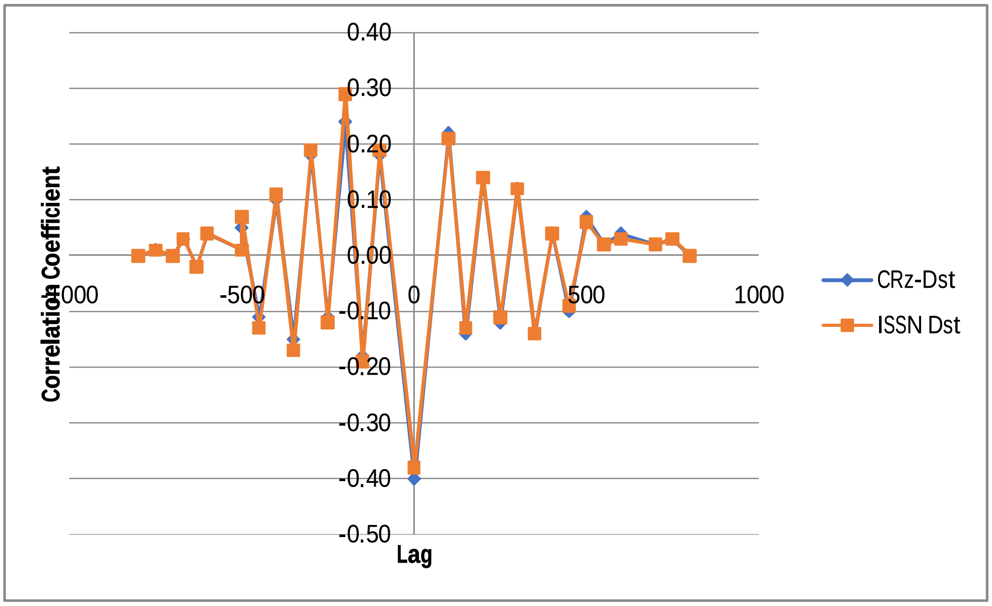

Figure 2.Lag against Correlation Coefficient of Geomagnetic Dst index CRz-Dst and ISSN-Dst.

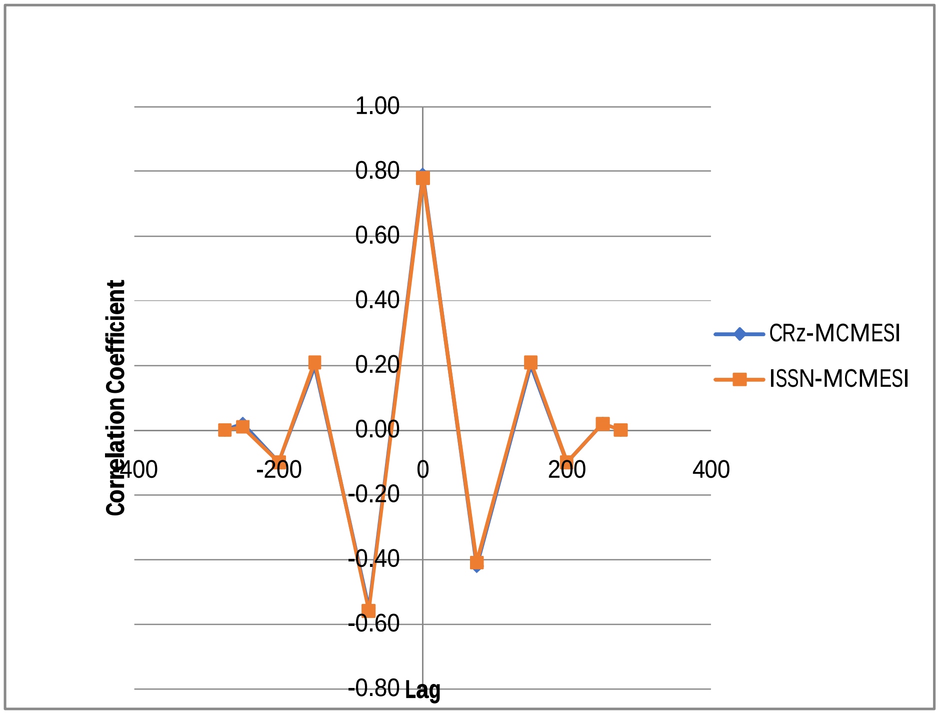

Figure 3. Lag against Correlation Coefficient of CRz-MCMESI and ISSN-MCMESI

The results are as follows:

1) The temporal variation of CRz describes SSA better than ISSN does.
2) CRz shows very good agreement with ISSN (r = 0.98) and also shows generally higher correlation and lower time delays with studied indices compared to ISSN.

We would like to start our discussion with,, which introduced the FPP for each sunspot group by using the number of produced flares for each modified Zurich class for the 2002–2022 time period. We recalculated the FPP based on the peak fluxes of produced flares for each sunspot group during the period between 2002 and 2022. In order to calculate FPP, M class X-ray flare peak flux was taken as a reference. C class flare peak flux was then divided by 10; X class flare peak flux was multiplied by 10. Thus, all flares were converted to M class. Note that the FPPs obtained in this study show very good agreement with previously calculated ones with one difference: the FPP of all Zurich classes decreased a small amount except for the F class, which increased remarkably.

As shown in Eq. (1), all sunspot classes have the same weight in daily sunspot number calculation. However, both the numbers of observed sunspots and sunspot areas are quite different according to their Zurich class: A and B classes describe very small sunspot groups, while E and F classes describe complex and strongly evolved sunspot groups. Analyzed sunspot counts of different sunspot groups in 4 categories and concluded that the temporal behavior of each category is quite different during a cycle. In this study, it is calculated the FPP of those groups and found that their FPPs differed drastically. We then recalculated the daily total sunspot number according to the FPPs of those classes as shown in Eq. (2). We found that the new sunspot number data (CRz) show higher correlation with SSA than ISSN. Thus, we may argue that CRz describes the solar activity better than ISSN.

Compared sunspot numbers and the MCMESI, Ap, and Dst indices with each other. They conclude that the MCMESI has been confirmed to be an index that can represent solar activity and geomagnetic indices at the same time. In this study, we compared CRz with the same indices that they compared and found that the results of cross-correlation between CRz and other indices are generally higher compared to ISSN. Therefore, it would be better to use the proposed equation, Eq. (3), in the calculation of the daily total sunspot number.

Analyzed correlations between yearly mean solar indices (sunspot number, group sunspot number, and cumulative sunspot area) and geomagnetic indices (Ap and Dst) between 1960 and 2001. They reported the correlation coefficient of sunspot numbers with Ap and Dst as follows: 0.55 with a time delay of 2 years, and –0.59 with no delay, successively. Here we used the monthly data between 2002 and 2022 and found the correlation coefficients of CRz with Ap and Dst to be 0.37 with a time delay of 6 months and –0.40 with no delay. Although the results may seem different, these differences mainly come from the temporal resolution and also from different time intervals used in the studies.

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