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Comparison between variations in solar UV radiation and sunspot parameters with Mg II daily index as a proxy

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ABSTRACT

Solar UV radiation influence the Earth's climate and upper atmosphere. The UV emission from the Sun modulates with the sunspot cycle with an 11-year periodicity. The variations in UV, EUV, and X-rays emission are significant during the solar cycle evolution compared to the visible part of the spectrum. The h & k lines of the Mg II spectra emitted from the chromosphere represent the solar UV variability. The sunspot's magnetic fields and dynamics are responsible for the UV and EUV emissions from the solar chromosphere and corona. This paper compares the Mg II core-to-wing ratio of the h & k lines observed at 278 nm wavelength (obtained from Solar Backscattered Ultraviolet Spectrograph (SBUV) instrument onboard the NOAA satellite) with the sunspot area parameter obtained from Royal Greenwich Observatory. When the sunspot group area is small, there is a linear relationship between the sunspot group area and the Mg II index. But a non-linear relationship between the two is observed for the large sunspot group area. There is no phase delay between the appearance of sunspot groups on the solar photosphere and the emission from the Mg II doublet. Apart from 11-year periodicity, we observed common 4.7, 3.2, and 2.2-year periodicity in both the data sets, suggesting the Mg II index is related to the sunspot parameters.

1. Introduction

Sunspots are dark structures visible on the Solar photosphere. The plages are bright features seen in the chromosphere part of the sun. Both features are magnetic in origin, but the former have intense magnetic fields (∼3000 G), and the latter has moderate magnetic field strength (∼1000 G). Their appearance and disappearance from the sun have an 11-year periodicity [1]. Sunspots and plages appear more on the sun during solar maxima and a few or none during solar minima. The presence of sunspots and plages could enhance solar UV and EUV irradiance.

The solar upper chromosphere, transition region, and corona emit ultraviolet (UV), Far UV (FUV), and extreme UV (EUV) wavelength regions of the electromagnetic spectrum. Solar UV radiation is responsible for producing and destroying the ozone layer in the Earth's atmosphere. The existence of the ionosphere is because of solar EUV radiation. The intensity of the solar UV, FUV, and EUV determines the height of the Earth's atmosphere [2]. The temperature reversals seen in the Earth's atmosphere (such as troposphere, stratosphere, mesosphere, and thermosphere) are caused by the absorption of solar UV and the complex chemical and dynamical phenomena occurring in the Earth's atmosphere.

The areas of sunspots surrounded by plages (called active regions), network and enhanced network all show brightening in UV and EUV [3]. The amount of radiant flux emitted from active regions differs from the networks. The UV and EUV flux emitted by active regions are more than the network. The radiant flux also depends on the angular position of the active region on the solar disk. The solar UV, FUV and EUV emission is modulated by solar rotation and varies with the solar cycle. But it is found that the solar cycle variations of UV flux are more than rotational modulation [4]. The solar cycle variations in UV and EUV are larger for the emission lines than the continuum.

The Mg II lines emitted from the chromospheric features and their flux varies with the solar cycle [5]. The Mg II lines exhibit similar properties as the Ca II H & K lines. The Mg II h & k lines have 279.7 and 280.4 nm wavelength and it falls near the UV range. These wavelengths can be observed from space-based observatories continuously without being affected by clouds, lack of observers and daily problems. The observations of the sun in this wavelength started during the 1970s, either in the imaging mode or in the spectral mode with the sun as a star.

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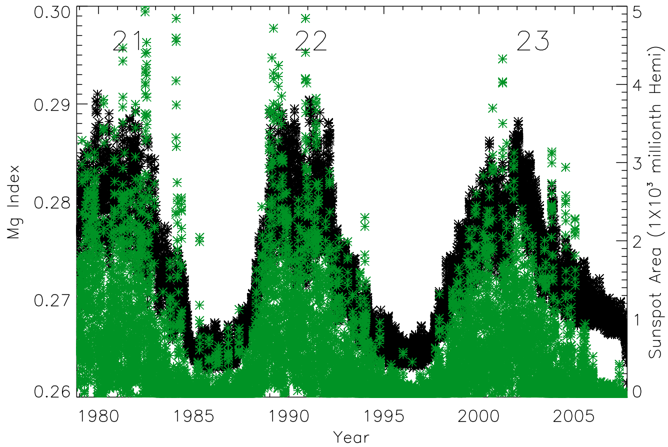

Fig. 1. Superimposed plot of the daily Mg II index (black star) and the sunspot area (green star) are plotted for solar cycle 21, 22, and 23.

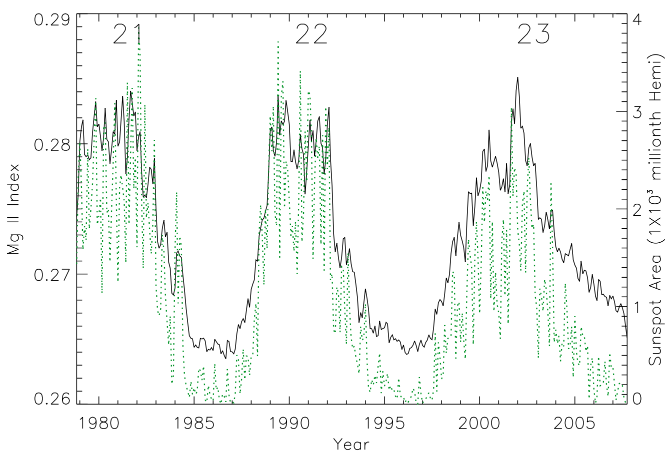

Fig. 2. The monthly averaged Mg II index (black) and sunspot area (green) are plotted against time for the solar Cycle 21, 22, and 23.

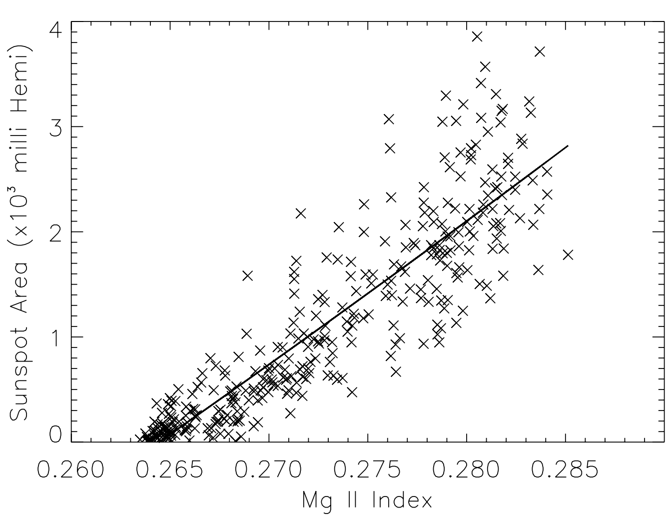

Fig. 3. A scatter plot between Sunspot area versus Mg II index.

This paper presents the results of the solar cycle variations of solar UV radiation in the Mg II h & k index as a proxy and compares the variations with the sunspot area cycle. We also present the results of periodicity found in the data set.

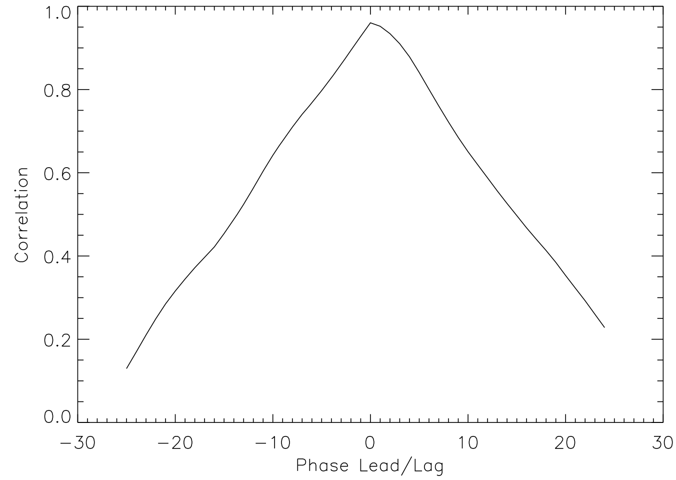

Fig. 4. A plot of phase difference between Sunspot Area and MG II Index.

2. Data and analysis

Like Calcium, magnesium is one of the most abundant elements in the solar atmosphere. The spectral lines of neutral and ionized Mg provide an excellent diagnostic tool to probe the solar photosphere and chromosphere. Among many lines of Mg, the resonance doublet of Mg II h (279.55 nm) and k (280.27 nm) emission lines near UV are the strongest and used frequently to study the characteristics of the chromosphere.

The scattered light in the instruments affects the spectral line strength and it changes with time. To overcome this problem, the core-to-wing ratio has been used [6,7]. This has been computed using the equation [8], Mg index $= 4(I_{279.8} + I_{280.0} + I_{280.2})/3(I_{276.6} + I_{276.8} + I_{283.2} + I_{283.4})$ where, $I_{279.8}$ is the intensity of the solar spectrum at 279.8 nm and so on. The data was collected from November 1978 to October 2007 from Solar Backscattered Ultraviolet Spectrograph (SBUV) instruments onboard the NOAA series spacecraft. The Mg II index data is made available to the public through https://www.ngdc.noaa.gov/stp/solar. There are a few data gaps in the Mg II index which is completed by interpolating the neighboring available data. The sunspot area data has been compiled by the Royal Greenwich observatory (RGO) and made available to the public through the https://solarscience.msfc.nasa.gov/greenwch.shtml webpage. The daily sunspot area data for the same period of Mg II index data coverage is obtained from RGO. These data sets are used to study the long-term variations of UV spectral irradiance along with the sunspot area.

3. Results

3.1. Solar cycle variations in Mg II index

Fig. 1 shows the superimposed plot of the Mg II index (black star) as a function of time. In the same plot, overlay the sunspot area for the same period is shown in the green star symbol. The amplitude of the sunspot area in cycles 21 and 22 is larger than in cycle 23. A similar amplitude decrease pattern is also seen in the Mg II index. It is observed that during solar minima, the sunspot area drops to zero. On the other hand, the Mg II index does not drop to zero, but it stays at some minimum level. This means that apart from sunspots and plages, there are some other magnetic features contributing to the enhancement of the Mg II index.

Fig. 2 shows the monthly averaged Mg II index for Cycles 21, 22, & 23. In the same plot, the monthly averaged sunspot area is shown in green color. A comparison of the Mg II index and sunspot area data suggests that the pattern of occurrence of the peak and length of the cycle appears similar in both data set. The dip and enhancement in the Mg II index follow the sunspot activity. For example, in cycle 22, there

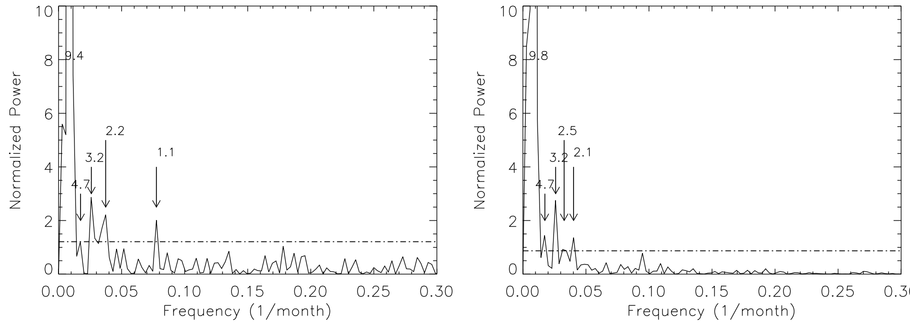

Fig. 5. Plots showing the power spectrum for the sunspot area (left) and Mg II index (right) time series. The horizontal dot-dash line indicates the 3σ level of the normalized power. A similar type of periodicities are observed in sunspot number [9] and plage area time series [10].

was a drop-in sunspot activity in 1990. A similar dip in the Mg II index could be seen at the same time. A similar pattern is observed in cycle 23, between 2001 and 2004 (see Fig. 2).

The plot also shows that the Mg II index does not reach zero during the solar minimum. This means that there is a background magnetic field or small-scale magnetic field which is contributing to the Mg II index. The minimum to maximum change in the Mg II index is about 6% meaning the sunspot groups contribute about 6% change in the Mg II index from the background level.

4. Relationship between the sunspot area and Mg II index

We plot a scatter plot between these two parameters to find the relationship between the Mg II index and sunspot area (Fig. 3). Though the time series data of the Mg II index and sunspot areas showed a one-to-one relationship, the scatter plot showed a non-linear relationship between these two parameters. However, the two parameters correlate well, with 0.92 as the coefficient value. The scatter plot shows that the spread is small for small sunspot group areas and large for large group areas. A gradient expansion least-square fit to the data points gave the following relationship between the two data sets,

$$SGA = 242.7 \times Mg^{1.97(\pm 0.54)} - 17.5$$

This kind of non-linear relationship is found between the sunspot area and number as well [9]. But it is not clear why larger sunspots show a different relationship than smaller ones.

5. Phase difference between sunspot area and Mg II index

Fig. 4 shows a plot between the correlation coefficient and the phase. The negative number indicates the phase lag, and the positive indicates the lead. The correlation coefficient is computed between the sunspot area and the Mg II index. From the plot, it is clear that there is no phase shift between these two, indicating that these two parameters are highly correlated at no time delay.

6. Periodicity in Mg II index and sunspot area time series

The fast Fourier transform-based power spectrum analysis is employed to find the periodicity in time series data. Fig. 5 shows the power spectrum of the sunspot area (left) and Mg II index (right) time series. The peaks above the 3σ level are considered a highly significant period. First, the primary 9.4 and 9.8 years periodicity is seen in the sunspot area and Mg II index time series. This periodicity is close to the well known 11-year periodicity. The following common periodicity is 4.7 years, seen in both time series. Quasi-biennial oscillations such as 3.2 and 2.2 years are seen in both time series. The 1.1-year periodicity is seen in the sunspot area time series, but its signature is small, below the 3σ level in the Mg II index.

7. Discussions and conclusions

In the absence of long-term UV and EUV radiation data from the sun, the Mg II core-to-wing ratio, the Mg II index, is used to study chromospheric activities. The correlation between the Mg II index and UV, EUV, and sunspot number was observed in the past. In this study, we used the Mg II index and sunspot area parameter and found the following results [11]. The Mg II index time series highly correlates with the sunspot area time series. But, when the sunspot group area goes to zero during the minima, the Mg II index does not reach zero. This indicates that not only do the large-scale magnetic fields, such as sunspots, contribute to the intensity of the Mg II index, but the small-scale network magnetic fields also contribute to the Mg II line intensity. This causes the Mg II emission not to reach zero during the solar minima [8]. The small sunspot group area shows a linear correlation between the two. But, the larger group area shows a non-linear relationship between the two. This means there could be different heating mechanisms of the chromosphere at the small and large-scale magnetic structures [4]. We have found no phase difference between the two-time series, indicating that magnetic fields are responsible for the observed Mg II index [9]. Apart from 11-year periodicity, the time series exhibit quasi-biennial oscillations [11]. This result indicates that the Mg II line formation closely follows the underlying sunspot magnetic fields. In the future, we would like to extend this study to solar cycle 24 and the rising phase of cycle 25.

CRediT authorship contribution statement

(G) Chandrika: Data download, Formal analysis, Writing – original draft, Writing – review & editing. **(B) Ravindra:** Analaysis, Writing – review & editing. **Vijay Kumar Doddamani:** Review and Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data is available online and the link is already given in the manuscript.

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