Long-Term Datasets for the Understanding of Solar and Stellar Magnetic Cycles
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Correlation of the New Sunspot Number and Geomagnetic aa Index in the Years 1900-2013

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Abstract. The recalibration of the sunspot number series has established a new standard version for sunspot time series that requires updating of prior results based on the calibration. These recent sunspot number corrections mean a change in the results of the previous correlational studies of ISSN with geomagnetic indices, such as the aa-index. In this paper, we investigate the correlation between the old and new sunspot numbers ISSN and SN and their relationship with the aa index through time series, using the methods of Echer et. al (2004), Verma & Trippathi (2016), Stamper et. al (1996), and Feynman (1982).

Keywords. Geomagnetic activity; Solar activity; Sunspot number; aa index

1. Introduction

Geomagnetic indices provide a long homogenous data base that can give information on the state of the Earth's magnetic properties. In particular, the aa index, which gives measurements of geomagnetic disturbance every day since 1868 is probably the most efficient for investigating the complexity of geomagnetic activity, which is caused by the interaction of the magnetosphere with solar agents in the interplanetary medium (Georgieva *et al.* (2005), Hathaway & Wilson (2006)).

The sunspot number has been a comprehensive source of data in solar and astrophysics studies as it provides both quantitative and qualitative solar references since its first observation 400 years ago. Over these centuries, the Wolf sunspot number, also known to be the International Sunspot Number (ISSN), has been the standard measurement of sunspot number.

It was only this recent when Clette & Lefèvre (2016) introduced the new sunspot number, SN, that corrected up to 20% of the original data series. The recalibration includes the suppression of the 0.6 Wolf-Wolfer conversion factor and the elimination of the 0-11 quantification that causes the overestimation of sunspot numbers among various observatories.

In this study, we analyzed the relationship between the new sunspot number and the aa index as compared to the old sunspot number through time series analysis.

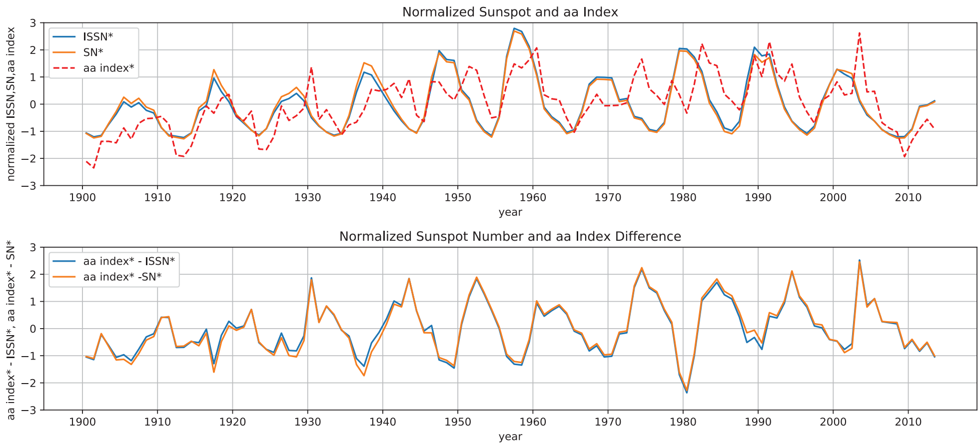

Figure 1. (a) Normalized annual means of aa index (dashed line) and normalized annual means of old and new sunspot number (solid line) on the year 1900-2013.(b) Difference between the normalized aa index and the old and new sunspot number.

2. Methodology

The correlation of the annual means of the sunspot number and geomagnetic aa index was studied by following the methods done by the following authors:

1 *Echer et al. (2004)*

We determined the long-term correlation between the sunspot number and aa index by following the cross-correlation and 11-year running mean done by Echer *et al.*(2004).

2 *Verma & Trippathi (2016)*

We used the correlative analysis done by Verma & Tripathi (2016) by taking the linear regression of sunspot number and aa index.

3 *Stamper et. al (1999)*

We followed the analysis done by Stamper *et al.*(1999) by getting the normalized values of the sunspot number and aa index given by

$$X^* = X - < X > / \sigma, \tag{2.1}$$

where $< X >$ is the mean and σ is the standard deviation, and then determining the variations of the difference of the normalized aa index (aa*) and normalized sunspot number (ISSN*, SN*). Afterwards, we analyzed the 11-year running mean of the normalized values of the geomagnetic aa index and sunspot number.

4 *Feynman (1982)*

We followed the work of Feynman (1982) to examine the observed background variation in the sunspot and aa index time series that peaked around 1970s. By defining aa index as a function of sunspot number, we can express it as

$$aa = aa_R + aa_I, \tag{2.2}$$

where aa_R and aa_I are the in-phase and out-of-phase aa index component relative to the sunspot cycle, respectively.

3. Results and Discussion

Following Echer *et al.* (2004) analysis, we found that the largest cross-correlation coefficient between ISSN and aa index is $r = 0.65$ with a lag year of 1 (almost the same to

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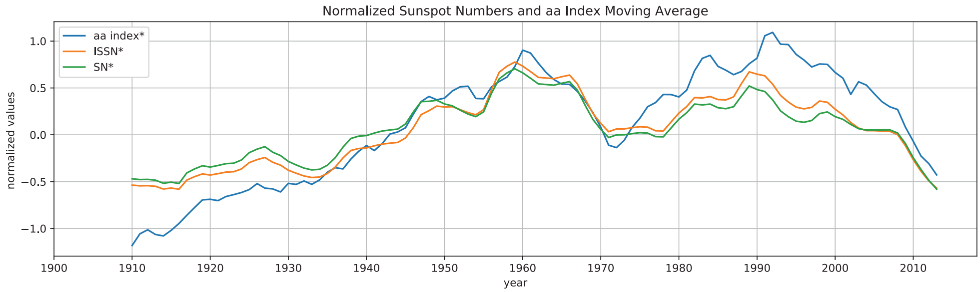

Figure 2. 11-year running mean of the normalized old and new sunspot number and aa index values.

Echer *et al.* result of $r = 0.66$) while a relatively lower correlation for SN and aa index, $r = 0.63$, lag of 1 year. Furthermore, at the 11-year running mean values, r is found to be 0.93 at lag 0 (again, almost the same with Echer *et al.* result of $r = 0.94$) for ISSN and aa index, while $r = 0.89$ at lag 0 for SN and aa index. The results on the smoothened data indicates that large time scales on geomagnetic and solar activity have higher correlations as it is affected by the long-term components in the solar activity.

In addition, a positive correlation coefficient, $r = 0.56$, (almost the same with Verma & Tripathi (2016) result of $r = 0.55$) and a correlation significance, p-value = 1.36e-10 were obtained for ISSN vs aa index, while a relatively lower $r = 0.53$ and p-value = 1.22e-09 were obtained for the SN vs aa index.

Similar to Figure 2 of Stamper *et al.* (1999), Figure 1a confirms the trend of the aa index that seems to lag behind the sunspot number because or the increasing amplitude of (aa*-ISSN*, SN*), where R is also referred as the sunspot number. Peaks of Figure 1b were observed when the aa index tended to have higher values than the sunspot numbers. However, in 1980 the aa index became relatively low while the sunspot approaches its maximum when the greatest minima of the aa*-ISSN*, SN* occurred. Moreover, we observed that the trend in the variation of the normalized aa index in Figure 2 is almost the same, but quite larger than the normalized sunspot number where clear rises were observed in 1900-1960 and 1972-1992 while a decrease between 1960 and 1972.

Comparing the aa index and the sunspot number suggests that the occurrence of each variation is almost compatible to the other. Figures 3a and 3b show the aa index as a function of ISSN and SN, respectively, for the years 1900-2013 (c.f. Feynman (1982)). We observed that most of the data points lie above the minimum line, and are more randomly scattered within 5nT-30nT aa index. In addition, we found that the distances of each solar maximum from the minimum line were about 0nT-8nT, such that the geomagnetic activity during the solar maximum is near to its minimum.

From the equation of the minimum line, we verified Feynman (1982) conclusion that the geomagnetic aa index can be decomposed into two periodic variations which are nearly 180° out of phase with one another and are given by Eqs. (3.1) and (3.2) for SN and ISSN, respectively:

$$aa_R = 0.12(ISSN) + 5.81, \tag{3.1}$$

$$aa_R = 0.08(SN) + 5.74. \tag{3.2}$$

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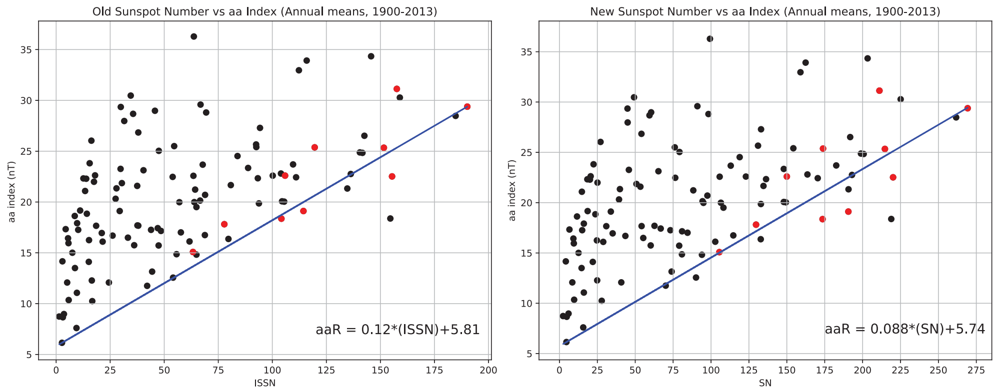

Figure 3. (a) ISSN vs aa index.(b) SN vs aa index. Red dots indicate the sunspot maximum per cycle.

4. Conclusions

From the methods of the four cited studies, we found that the correlation of the annual means of the old sunspot number ISSN and geomagnetic aa index has a relatively higher correlation coefficient and significance than the annual means of the new sunspot number SN and geomagnetic aa index in the years 1900-2013. Although both data series obtained strong positive correlation to the aa index, ISSN possessed a higher correlation than the SN series. Normalized and smoothened values of the annual mean of ISSN also showed higher correlation with the filtered annual mean values of the aa index than the filtered annual mean values of SN.

The observed lower aa index values at the peak of the sunspot cycle confirmed that the variation of the sunspot number and aa index have dramatically changed over time. Wherein the aa index appeared to be more dependent on the sunspot cycle during the first phase of the 20th century, but then later appeared to be more dependent on other solar agents that peak at the declining phase of the solar cycle (Kirov *et al.* (2015), Simon (1979)).

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