A comparison of BAA Solar Section white-light measurements

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This paper compares the BAA white-light measurements made during Solar Cycle 24. The main purpose is to assess whether there are any differences in the recorded long-term characteristics of solar activity for observers who determine the number of groups, the sunspot number and/or the BAA quality number (based on type of group). A comparison is also performed between the International Sunspot Number and the BAA sunspot number.

Introduction

Each month, over 50 BAA solar observers submit their daily observations to the Solar Section. These are used to form the activity summary tables in the Section's monthly *Newsletter* and in the *Journal* Solar Section 'Notes & News' reports. White-light measurements take the form of daily counts of one or more of the following: the number of sunspot groups (g), the sunspot number ($R = 10g + f$ where f is the number of sunspots) and the quality number (Q). The number of groups is for the whole disc, which may also be separated into the northern and southern hemispheres. These daily counts are averaged for all observers and then over all days of each month to give the mean daily frequency (MDF) values that are used to monitor the long-term sunspot activity of the Sun. The majority of observers report g (with an average of 49 during the 10 years since the start of Solar Cycle 24 in 2009); slightly fewer also report R (43) while fewer observers also report Q (11). An easy online form is available for the submission of white-light and hydrogen-alpha daily measurements.[1]

After showing the variation in the number of BAA sunspot groups during Cycle 24, this paper performs a comparison of solar activity over the cycle, based on each of the BAA g, R and Q measurements. This is to assess whether there are any differences in the measured activity depending on which type of measurement is made by the observer. The comparison is performed by (i) plotting g against R, and Q against R, together with a linear fit and (ii) plotting the ratio of R/g and R/Q for each month to assess if there are any differences depending on the time within the solar cycle. The paper then continues by examining outlier months in the g-against-R plot, which have more or fewer sunspots than expected compared to the linear fit. Finally, the paper compares the monthly International Sunspot Number with the BAA sunspot number during Cycle 24.

Cycle 24

After a prolonged solar minimum, Cycle 24 began in 2009 and peaked in early 2012 and mid-2014. This is shown in Figure 1, which is based on BAA Solar Section sunspot group observations (the red curve is the average over 13 months). In comparison with previous cycles, Cycle 24 was the smallest since Cycle 14 which peaked in 1906. Although not unique, the double peak of Cycle 24 was quite pronounced and was the result of differing activity between the northern and southern solar hemispheres. Solar minimum was expected to occur during 2019.

Comparison of BAA g, R and Q measurements

To compare g, R and Q, the g and Q MDFs have been plotted against the R MDF for each month during Cycle 24 (the 10 years from 2009). Q is based on the type of sunspot group; the simplest groups consisting of one or more sunspots without penumbra have a low Q number, while the most complex groups have a higher Q number.[2] Figure 2 shows the plot of g against R together with a linear fit between the two MDFs (assuming an intercept at the origin), which gives $g = 0.0633R$ or $R = 15.80g$ and the r-squared goodness of fit as 0.986. Figure 3 shows a similar plot for Q against R where the linear fit gives $Q = 0.1801R$, or $R = 5.55Q$, and an r-squared value of 0.986. In both plots, as indicated by the r-squared value being close to one, there is a good relationship between g, Q and R.

How do the BAA g, R and Q MDFs compare throughout Cycle 24? Figure 4 shows the ratio of R and g MDFs during the cycle, together with a ratio of the 13-month smoothed R and g MDFs (shown in blue). Figure 5 shows a similar plot for R and Q MDFs. In both cases, the ratio shows more variability during solar minimum than during the rise, peak and fall parts of the solar cycle. This is particularly the case for the ratio of R and Q, where Q can have very small values during the minimum parts of the cycle. Within the main part of the cycle, the ratios do not significantly change although some variability is expected. This is due to the changing nature of the types of sunspot group seen during the cycle, with less complex groups seen during the rise/peak and more complex groups seen during the latter part of the peak and the fall of the cycle.

BAA *g* and *R* MDF outliers

Two outliers below and two outliers above the linear fit in the BAA *g* vs. *R* MDF plot in Figure 2 (shown in green and red, respectively) have been examined further to understand why these four months deviate from the linear fit. The number of groups, the sunspot number, the ratio of *R*/*g* and a deduced number of sunspots (using $f = R - 10g$) for these four outliers are shown in Table 1. Given that for the linear fit $R = 15.8g$, it can be seen that for 2014 February and 2014 September, *R*/*g* is greater than 15.8 and there is also a high number of individual sunspots. Meanwhile for 2012 August and 2016 March, *R*/*g* is lower than 15.8 and there is a low number of individual sunspots, especially for 2016 March.

Figure 6 shows the daily *R*/*g* ratio during 2014 February, where the red line is the Figure 2 linear fit ratio of 15.8. It can be seen that *R*/*g* was particularly high during the early part of the month. This corresponded to the passage of the complex Fkc group Active Region 11967,[3] which was the second-largest sunspot group of Cycle 24,[4] and another complex Ekc group, AR 11968, at a similar longitude as AR 11967 as shown in Figure 7. (The NOAA Solar Region Summary report information superimposed on the SDO/HMI images shows the AR number, group type and area in millionths of the Sun's visible hemisphere.) These complex groups contained many individual sunspots which thus increased the *R*/*g* ratio. The peak in *R*/*g* around Feb 15 was due to the presence of two complex groups, AR 11974 and AR 11977, as shown in Figure 8. Meanwhile the broad peak around Feb 23 was due to two nearby E-type groups, AR 11981 and AR 11982, as shown in Figure 9. The BAA Solar Section *Newsletter* for 2014 February describes these groups thus:[5]

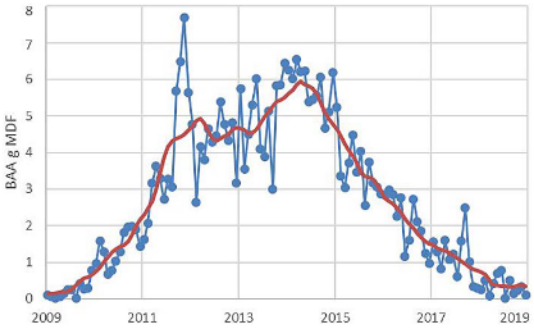

Figure 1. Solar Cycle 24, based on BAA *g* MDF measurements.

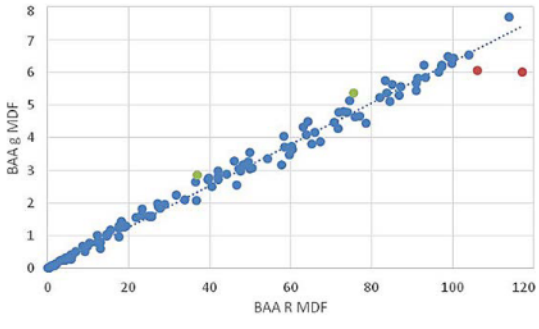

Figure 2. Comparison of BAA *g* and *R* MDF measurements.

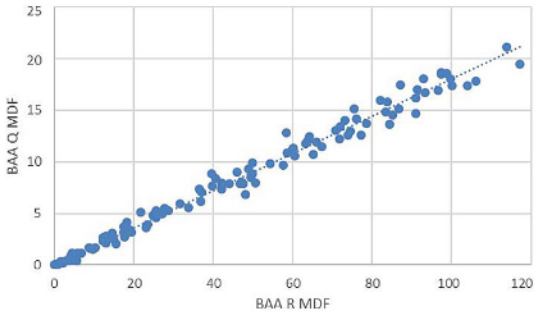

Figure 3. Comparison of BAA *Q* and *R* MDF measurements.

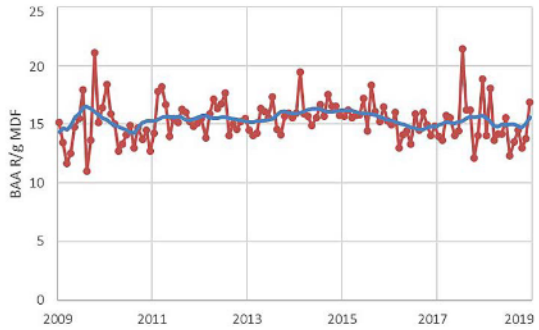

Figure 4. Ratio of BAA *R* and *g* MDF measurements during Solar Cycle 24.

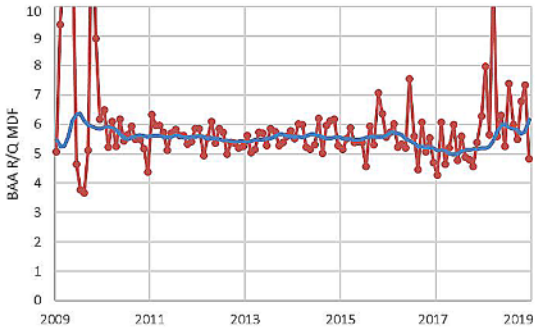

Figure 5. Ratio of BAA *R* and *Q* MDF measurements during Solar Cycle 24.

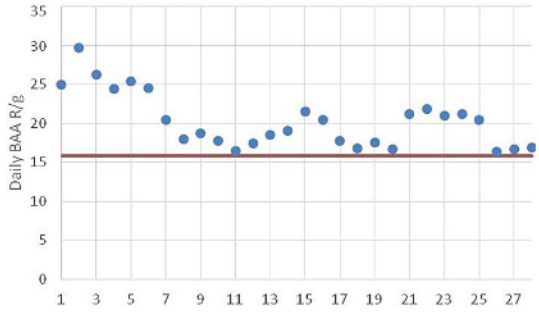

Figure 6. Daily ratio of BAA *R*/*g* during 2014 February.

AR 11967 S11°/112° (return of AR 11944). This group dominated the disc at the start of the month and was approaching the central meridian on Feb 1. It appeared as a complex Fkc group comprising small penumbral sunspots at the leading part of the group and a large asymmetric follower, with an irregular penumbral sunspot in between. It had an estimated area of 1,200 millionths of the Sun's visible hemisphere. On the following day, the three portions from the previous day had merged to form a large very irregular elongated sunspot. Within this there were many umbrae, the largest of which were towards the middle and following parts. Several small penumbral sunspots and pores were surrounding the main sunspot and the total area was 1620 millionths – an impressive sight. On Feb 5 the group was sprawling across the south-west quadrant, still dominated by the extensive asymmetric follower. By Feb 8 only an irregular Hkx sunspot was seen, nearing the western limb. AR 11967 was seen with the protected naked eye on Feb 1, 2, 3, 4, 5, 6 & 7.

Table 1. MDF outliers during Cycle 24

Date	*g*	*R*	*R*/*g*	*f*
2014 Feb	6.02	117.25	19.48	57.05
2014 Sep	6.05	106.12	17.54	45.62
2012 Aug	5.38	75.47	14.03	21.67
2016 Mar	2.85	36.99	12.98	8.49

AR 11968 N11°/112° remained on the disc from 2014 January and was type Eac on Feb 1, with an area of 220 millionths. It consisted of a string of small penumbral sunspots and by Feb 2 had developed a larger follower, but lost some of the leading penumbral sunspots to just pores. On Feb 4 the group underwent growth within its following end, north of the main structure, and by Feb 5 it was a substantial oval of penumbral

sunspots, type Ekc. On Feb 8, close to the limb, it had returned to a collection of several penumbral sunspots.

AR 11974 S11°/352° appeared on the south-east limb on Feb 6, type Csi. On Feb 9, pores started to develop to the east of the main structure and by Feb 10 the group was type Fsi. The following day the group was a sea of complex small pores and cores, in an arrowhead formation following a relatively small penumbral leader with a divided umbra. The group continued to develop over the coming days, the leader sporting a triple umbra by Feb 13. On Feb 15 the group had an estimated area of 830 millionths and comprised many irregular penumbral sunspots. It was of a similar appearance and size on Feb 16 when seen approaching the western limb. The group was reported visible to the protected naked eye on Feb 15 & 16.

AR 11977 S11°/291°. Travelling east of AR1976, this group rounded the limb on Feb 11. The group consisted of a substantial penumbral leader with smaller sunspots trailing, type Eao, and was accompanied with bright faculae on Feb 12. On Feb 13 a light bridge was seen in the umbra of the largest sunspot, and a rather curious northwards displacement of the arc. The group crossed the central meridian on Feb 16, type Ekc, and showed a good deal of structure. By Feb 18 the group had undergone rapid decay and by Feb 19 was type Cai. The group continued to fade and rounded the limb on Feb 22.

AR 11981 S06°/215° and AR 11982 S11°/206°. Both groups were near the south-east limb on Feb 18. The two groups were travelling close together, with AR 11981 being the more northerly and westerly of the two. On Feb 21 the largest of the pair was AR 11982 at 340 millionths. On the following day it became more difficult to separate AR 11981 and 11982, as there was only about 5° difference in latitude and the following part of AR 11981 was overlapping in longitude with AR 11982. There was a greater longitude overlap between these two groups on Feb 24, appearing as a great triangular scatter of sunspots on the solar disc. As the groups progressed towards the south-west limb, they began to decay. These groups were seen approaching the western limb on Feb 27 amid a very large area of faculae and began to round the limb on Feb 28.

The daily *R*/*g* ratio plot for 2014 September is shown in Figure 10, where there is a peak in *R*/*g* of around 20 on Sep 9 and a much higher peak on Sep 27. Figure 11 shows that on Sep 9 there was an Ekc group in the southern hemisphere (AR 12157) and a Dkc group in the northern hemisphere (AR 12158). Both groups contained numerous sunspots. On Sep 27, as shown in Figure 12, there were nearby complex groups containing many sunspots in the southern hemisphere – ARs 11271, 11272 and 11273. There was also a complex group in the northern hemisphere, AR 12175, but this did not contain many sunspots. The *Newsletter* for 2014 September describes these groups as follows:

AR 12157 S13°/100° rounded the south-east limb on Sep 5. By Sep 7, the group was type Eki and considerable detail was visible around its following component, with lesser activity

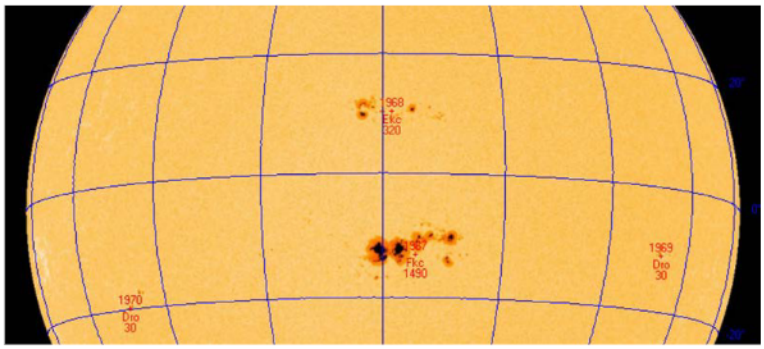

Figure 7. SDO/HMI image from 2014 Feb 3.

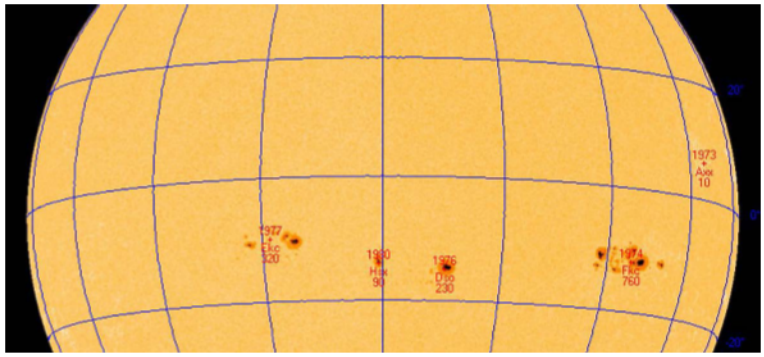

Figure 8. SDO/HMI image from 2014 Feb 15.

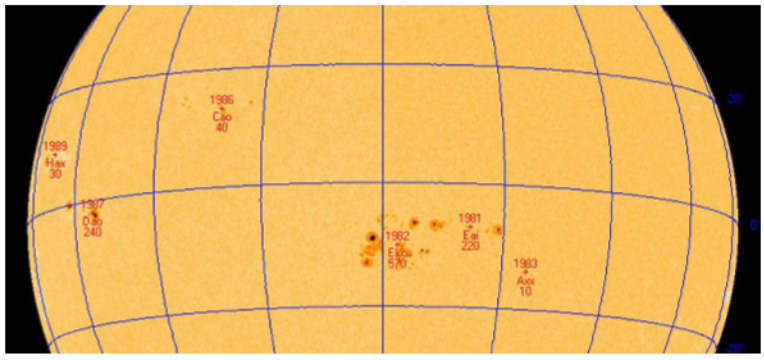

Figure 9. SDO/HMI image from 2014 Feb 23.

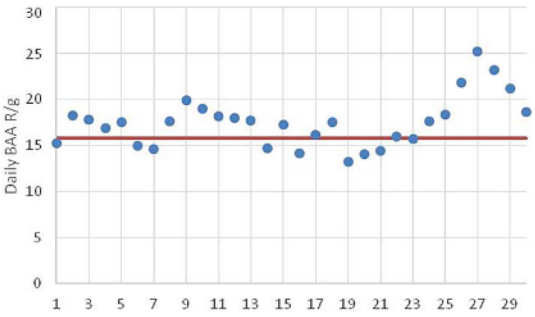

Figure 10. Daily ratio of BAA *R*/*g* during 2014 September.

following its smaller leading component. By Sep 10 the group was straddling the central meridian and continued to develop a retinue of sunspots, adding to this already complex bipolar group. Signs of decay were evident on Sep 11, which continued on Sep 12. Decline was rapid thereafter, with a small sunspot remnant departing over the south-west limb on Sep 16.

AR 12158 N17°/088° also appeared on the disc on Sep 5, but over the north-east limb. By Sep 7 the group sported a large penumbral sunspot with an obvious light bridge that dominated,

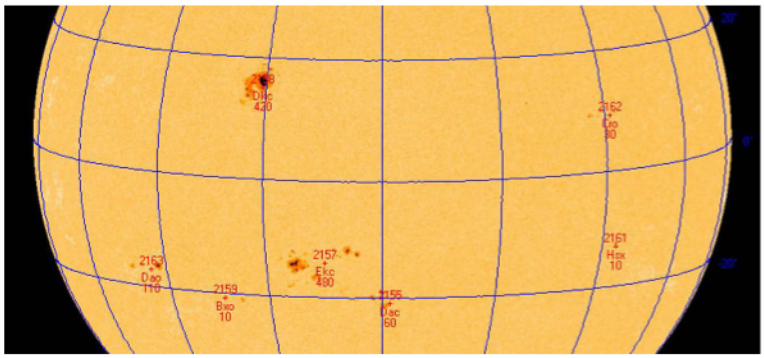

Figure 11. SDO/HMI image from 2014 Sep 9.

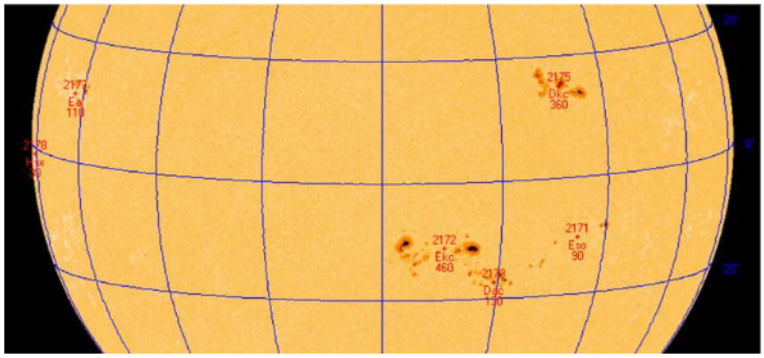

Figure 12. SDO/HMI image from 2014 Sep 27.

with just a few small sunspots to its south. The group was type Dko, with an area of 330 millionths which increased to 560 millionths. It was type Hkx by the following day, having lost accompanying smaller sunspots. The main sunspot was quite irregular, including a very distinctive light bridge with a bright spot at its centre and a lot of surrounding structural detail. The appearance of the group changed again on Sep 9 with many small penumbral sunspots appearing around the main penumbral sunspot. The light bridge was not seen. By Sep 10 the main penumbral sunspot had split into two, with many pores appearing around these and the total area reduced to 380 millionths. The group continued to decay and was estimated at 300 and 230 millionths on Sep 12 & 14, respectively, type Dkc and Dac. On Sep 14 the group comprised of just a few small penumbral sunspots and was seen approaching the north-west limb on Sep 15 amid extensive faculae. The group was reported visible to the protected naked eye between Sep 7 & 12 inclusive.

AR 12171 S10°/263° appeared over the south-east limb on Sep 19. By Sep 21 the group had a divided umbra in its leading component and a follower, with a small pore on the northern edge of its penumbra. By Sep 22 the group was type Eac, with a developing patch of penumbra forward of its trailing component. The group crossed the central meridian on Sep 24 and by Sep 26 was just 100 millionths in area. However on Sep 27 the group 'joined forces' with AR 12172 and AR 12173 to give the appearance of a complex collection of sunspots, all at similar latitudes and spanning some 35° in longitude as they approached the south-west limb.

AR 12172 S09°/239°. The leading sunspots started to appear over the south-east limb on Sep 20 and the group was fully on the disc by the following day. The leader was a double sunspot arranged north/south and the follower a large penumbral sunspot with a roughly triangular umbra. The group continued to develop over the next few days and a bright white sunspot appeared on the north-east edge of the umbra in the leading component. A wedge-shaped light bridge was also seen in the process of development on the northern edge of the umbra on Sep 24. The group was straddling the central meridian on Sep 26 with an estimated total area of 610 millionths, type Ekc. By Sep 28 it had extended to type Fac at 470 millionths in area, and was associated with AR 12171 and AR 12173 (S15°/250°, type Dac, with an area of 250 millionths). This group was reported visible to the protected naked eye on Sep 22, 23, 25, 26 & 28.

In contrast, the *R*/*g* value for 2012 August and 2016 March, as shown in Figures 13 & 14, was close to the minimum possible (11, when each group has just one sunspot). An example of a low *R*/*g* disc is shown in Figure 15 for 2012 Aug 23, when there were five groups. All but one of the groups contained a single sunspot (the remaining group having just two sunspots). Thus the sunspot number was 56 and the *R*/*g* value was 11.2. Table 1 shows that in 2016 March there were fewer groups than in 2012 August and that they contained very few sunspots, which led to the *R*/*g* value being particularly low for most of the month.

Comparison of the BAA *R* and International Sunspot Number

The primary long-term measure of solar activity is the International Sunspot Number *Ri*,[6] for which monthly values are available back to 1749 and yearly measurements back to 1700.[7] Note that on 2015 July 1, the sunspot number series was replaced by a new improved version (version 2.0) that includes several corrections of past inhomogeneities in the time series.[8]

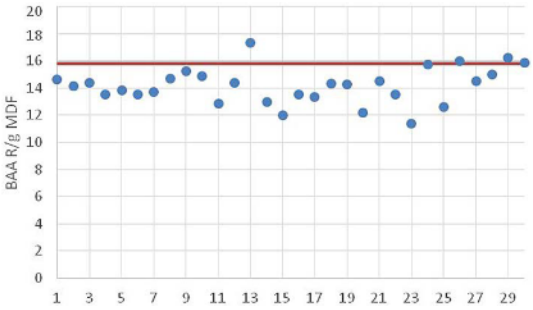

Figure 13. Daily ratio of BAA *R*/*g* during 2012 August.

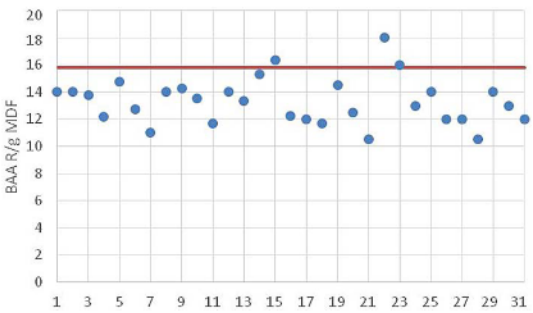

Figure 14. Daily ratio of BAA *R*/*g* during 2016 March.

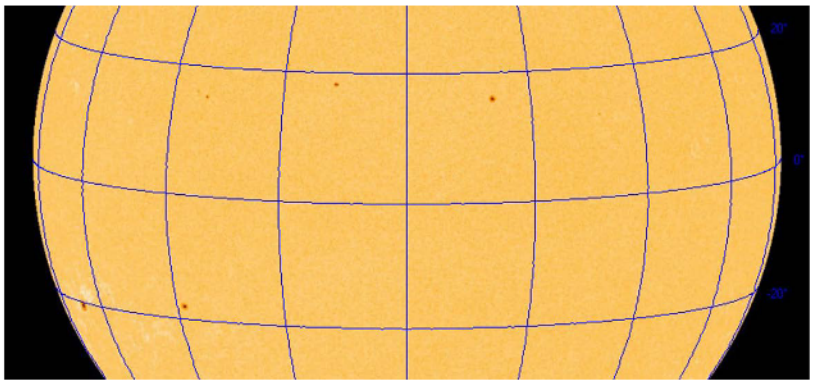

Figure 15. SDO/HMI image from 2012 Aug 23.

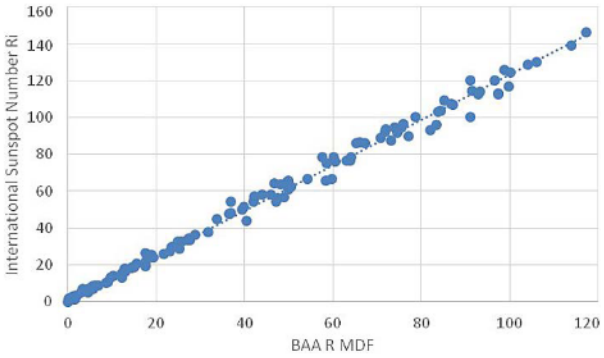

Figure 16. Comparison of International Sunspot Number *Ri* and BAA *R* MDF measurements.

A comparison of the monthly *Ri* and the BAA *R* MDF is shown in Figure 16 for Cycle 24 (the 10 years from 2009). Also shown is a linear fit where $Ri = 1.2349R$ or $R = 0.8098Ri$, with an r-squared goodness of fit of 0.993, which indicates a good correlation between the two sunspot numbers. Except during solar minimum, there are only small monthly variations in the ratio between *Ri* and the BAA *R* as shown in Figure 17.

Summary

By comparing the BAA white-light measurements of the number of groups, the sunspot number and the quality number, it has been shown that there is a good relationship between them. Thus, each of the measurements monitor the behaviour of solar activity during the solar cycle equally well.

It has been shown that outliers in the relationship between the number of groups and the sunspot number occur when there are many more or fewer sunspots within groups seen than that observed during other months of the solar cycle. It has also been shown that there is a good relationship between the International Sunspot Number *Ri* and the BAA sunspot number *R*, albeit with a factor of 1.23 to convert the BAA *R* to the *Ri*.

Acknowledgements

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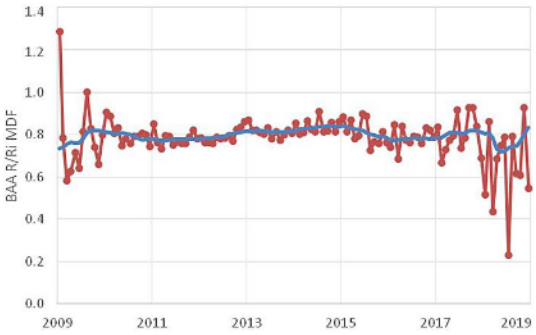

Figure 17. Ratio of *Ri* and BAA *R* MDF measurements during Solar Cycle 24.

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References & notes

1 Meadows P., 'The BAA Solar Section observation databases', *J. Brit. Astron. Assoc.*, **129**(6), 326–328 (2019)
2 Ventura F. J. & Tanti T., 'Analysing sunspot activity: A qualitative and quantitative approach', *J. Brit. Astron. Assoc.*, **98**(6), 282–286 (1988)
3 An active region (AR) number assigned to a sunspot group during its disc passage. Note: the AR number reached 10,000 in 2002 July. However, NOAA Space Weather Prediction Center (SWPC) products continue to use four-digit region numbers, with leading zeros. The BAA and many other solar organisations use the AR to identify sunspot groups (and in the shortened four-digit format for groups since 2002 July). This paper uses the full five-digit format, except for the NOAA Solar Region Summary report information superimposed on the SDO/HMI images.
4 Meadows P., Smith L. & Cook J., 'The larger sunspot groups of Cycle 24', *J. Brit. Astron. Assoc.*, **129**(4), 222–231 (2019)
5 BAA *Solar Section Newsletters*: **https://www.britastro.org/downloads/12691**
6 Sunspot Index and Long-term Solar observations (SILS), World Data Center for the production, preservation and dissemination of the International Sunspot Number: **http://sidc.be/silso/**
7 SILS, Sunspot number: **http://sidc.oma.be/silso/datafiles**
8 SILS, Sunspot number version 2.0: new data and conventions: **http://www.sidc.be/silso/newdataset**

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