Faculae Area as Predictor of Maximum Sunspot Number

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Abstract. We measured facular area from digitized images obtained from the Mt. Wilson Observatory for 41 days from selected dates between the years of 1965 to 1967, that is during the first two 2 ½ years of solar cycle 20. These facular area measured were then compared to the facular areas measured from the Royal Greenwich Observatory for the same corresponding dates. The comparison shows that the two data sets are linearly correlated and therefore this relationship can be used to calibrate our data in terms of RGO measurements. We show that the behavior of these calibrated data vs. time can be modeled by an exponential function, which can be used to derive smoothed values for the facular areas. After selecting only those measurements with area ≤ 1500 millionths of a solar hemisphere, we plotted these values against smoothed sunspot areas obtained from a 13-month running mean for the same corresponding days. A linear relationship is found, and the slope of the linear regression line is then used to predict the maximum sunspot number based on a model proposed by Brown and Evans (1980).

1. Introduction

The solar cycle is on average an 11 year period in which the sun undergoes changes in its magnetic activity. This corresponds to the formation and development of dark magnetic regions on the photosphere of the sun known as sunspots, and other solar phenomena. Sunspots form in regions with magnetic field strengths thousands of times stronger than that of Earth's magnetic field, which prevents convection from the sun's interior. This prohibition of heat flow results in the dark appearance of sunspots on the surface of the Sun because they are approximately 2000K cooler than the surrounding photosphere. Throughout a given solar cycle there is a progression from solar minimum, which is marked by the fewest number of sunspots observed on the surface of the Sun, to solar maximum, which is the time period containing the greatest number of spots observed on the surface of the Sun, during the 11 year cycle. The sunspot number, which is an index of the total number of spots on the disc, is given by the sum of the individual sunspots and ten times the number of sunspot groups (NASA/Marshall Solar Physics 2009). When the sunspot number is large this corresponds to a magnetically active sun, which results in a higher frequency of solar phenomena, such as solar flares and coronal mass ejections. These solar phenomena could have potentially direct affects on Earth, contributing to the disruption of telecommunications, power transmission networks, and even airline routing. For example, the 9 hour power outage in March of 1989 in Quebec Canada which occurred after a large solar storm resulted in over 300 million dollars worth of damage. Therefore, being able to predict the maximum amplitude of a particular cycle is a task of growing importance.

The Sun's magnetic field can also manifest itself on the surface of the Sun through structures that appear brighter than the surrounding photosphere, known as faculae. Zeeman measurements indicate that sunspots differ mainly from faculae in that they have a higher packing density magnetic flux tubes (Foukal 1993). As a result of faculae having smaller diameter magnetic flux tubes as compared to sunspots, the inhibition of vertical heat transport by the magnetic field is over compensated by the formation of a dip in the photosphere, from whose hotter sides radiation escapes more easily, forming hot spots on the surface of the Sun (Foukal 2004). Faculae also have a much longer lifetime than sunspots, typically between 200 to 300 days, where as sunspots have average lifetimes of around 2 weeks, or at most one solar rotation (Basu 2003). It is also important to note faculae always form in areas surrounding sunspots, and they sometimes form along the boundaries between granules. The boundaries between granules are lower in the Sun's photosphere than the granules, which are at the top of convection cells. Therefore these boundaries are brighter and hotter, forming faculae. According to Foukal (Foukal 1993) the ratio of faculae area to sunspot area in the beginning of a particular cycle is linear, with varying slope between differing cycles, as a result of constant packing density of magnetic flux tubes. However, as a cycle progresses towards the maximum the ratio of faculae area to sunspot area becomes nonlinear. This is a result of an increase in the area filling factor of magnetic flux tubes, which favors the formation of sunspots (Foukal 1993).

This study has three objectives. The first is to measure facular areas during the rising phase of solar cycle 20 from digitized Mt. Wilson images using modern computer techniques, and compare them to the area measured by the Royal Greenwich Observatory over forty years ago. The second is to use or measured facular areas and test the Brown and Evans (1980) model to check if it is in fact able to predict with reasonable accuracy the maximum number of sunspots at the peak of solar cycle 20. The third is to test the predictive capability of the model for other sunspot cycles, such as cycle 21. If it proves to be a good predictor then we can apply this technique to the current cycle 24 and future cycles. In section 2 of this paper we describe the techniques used to measure the facular areas from the digitized Mt. Wilson images. In section 3 we compare the maximum sunspot number obtained by the Brown and Evans (1980) model to that of already measured for solar cycle 20. In section 4 we present our conclusions.

2. Faculae Area

All facular area measurements were obtained from 41 Mt. Wilson digitized images from selected dates between the years of 1965 to 1967, for solar cycle 20. To ensure the most accurate measurements all images were analyzed by two people independently using the same procedure and criteria for determining what structures accounted for faculae on the solar disc. Due to the particular technique used to produce the digitized images the faculae appear as dark irregularly shaped regions on the sun, mostly seen near the limb independently or with associated spots, while the sunspots appear as bright structures, consisting of a bright umbra and less bright penumbra. To improve the contrast the images were flat-fielded using a low-pass filter to eliminate any large-scale intensity variation between the center and the limb of the solar disc. Figure 1 shows a typical example of a digitized image (9/26/1966) after the flat fielding procedure.

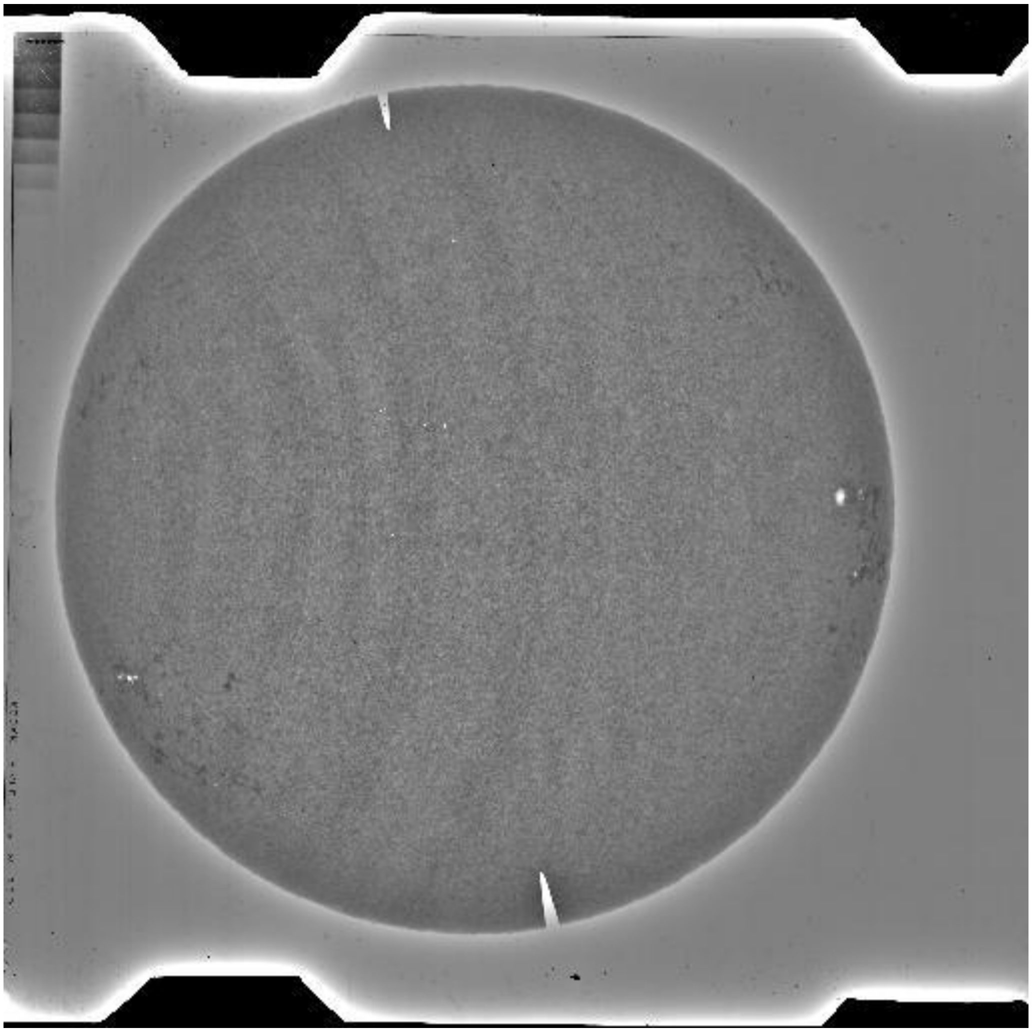

Fig. 1. Flat-field digitized Mt. Wilson image (9/26/1966) from solar cycle 20. Facular appear as dark structures and sunspots appear as bright structures.

Sunspots are also visible on the east and west limb of the image as white area. Faculae are more difficult to identify but they are the dark areas near the sunspots. Most faculae were seen towards the limb of the solar disc but there was no exclusion of poleward faculae, and all structures determined to be faculae were included in the calculation of total faculae area for a given image. All of the Mt. Wilson digitized images were analyzed using Interactive Data Language, or IDL. When using IDL the first step of the image analysis was to find the center and radius of the solar disc for each specified day of observation, which was done by fitting a circle around the disc. From that information we were then able to determine the location of the facula on the disc using procedures in IDL. This location is given In terms of radial distance r of the facular from the center using the following equation:

$$r = \sqrt{(x_c - x)^2 + (y_c - y)^2} \qquad (1)$$

Where x_c and y_c are the center coordinates of the disc laid out on a two-dimensional Cartesian coordinate grid, and x and y are the coordinates of the facula on the disc. After determining a particular structure met the criteria to be considered facula and after its position is obtained, the next step was to then calculate the area of the faculae. The tools in IDL allowed us to isolate the region of the facula by using color intensity techniques, and then area was calculated as the number pixels that were within the threshold of intensities selected. See figure 2 & 3.

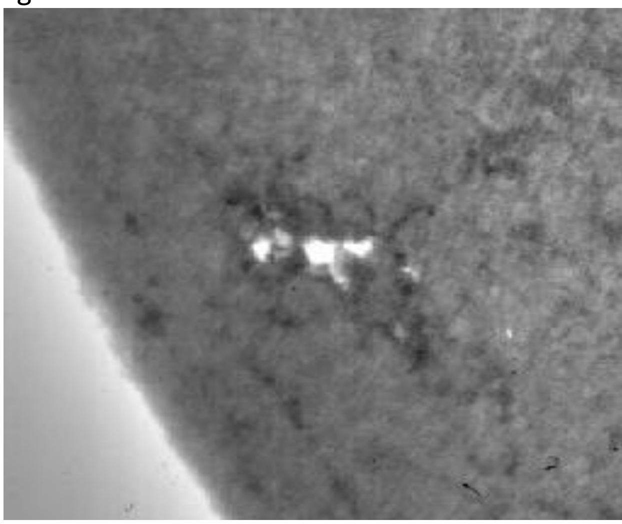
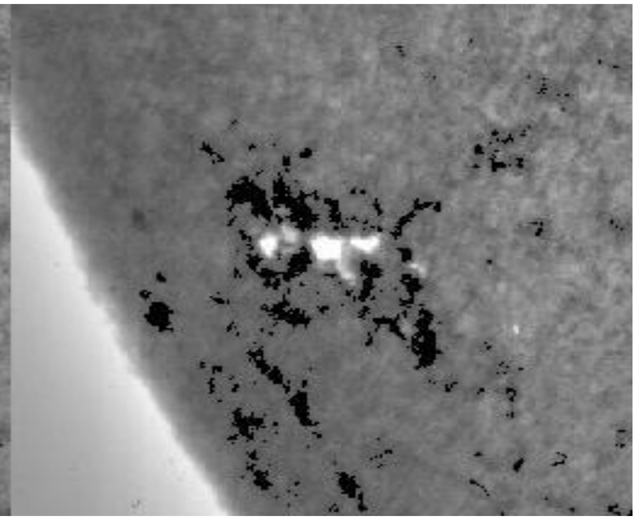

Fig. 2. Facula surrounding sunspot before color intensity techniques. Fig. 3. Facula surrounding sunspot after color intensity techniques.

These techniques were applied to all faculae observed for all 41 images. Because of the projection effect due to the spherical shape of the Sun, the measured area of a facula needs to be corrected by a factor that depends on the position of the feature in the solar disc. This factor is the cosine of the angle between the normal surface, and the location of the facula, and the line of sight to the observer. All measured area were then divided (normalized) by this factor μ, given by

$$\mu = \sqrt{1 - \left(\frac{r}{R}\right)^2} \qquad (2)$$

where *r* is the radial distance of the faculae and R is the radius of the disc. In addition, all total normalized areas for a given image were then divide by $2\pi R^2$ to scale our areas in units of millionths of the total solar hemisphere.

3. Maximum Sunspot Number Cycle 20

After facular areas from the archive of digitized Mt. Wilson images were measured for the 41 selected days between 1965 to 1967, they were plotted against the RGO facular area measurements for the same corresponding days. This is shown in figure 4 where $A_f^{'}$ represents our measurements.

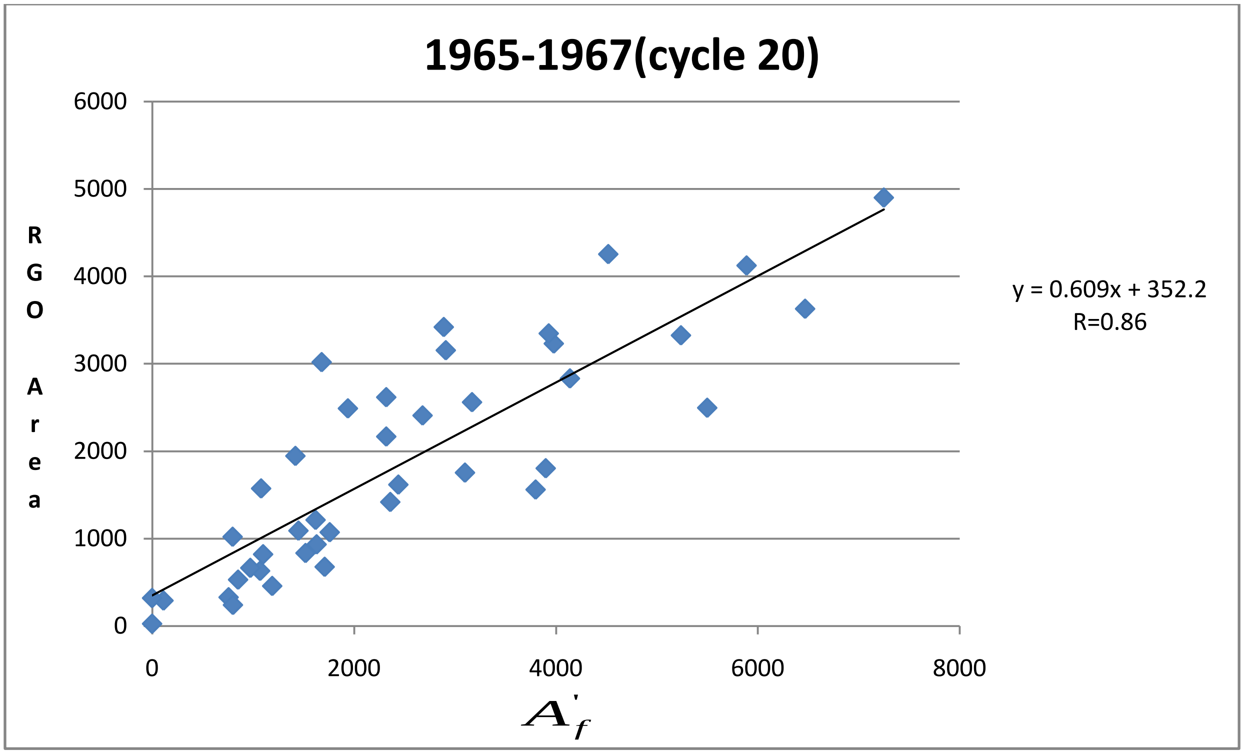

Fig. 4. A plot of the RGO vs. A_f', this shows a linear trend with a slope of 0.609 and a correlation of coefficient of 0.86

The plot shows a linear trend with a correlation coefficient of 0.86 and a slope of approximately 0.61. This particular value of the slope indicates that we typically measured greater facular areas then that measured by the RGO. Possible explanations for this could be a result of viewing different images, which were taken at different times of day, and different measuring techniques and criteria. The equation of the trend line as shown on the plot was then used as our calibration curve, putting our measurements on the same scale of the RGO measurements. We used this model to replace our measurements with the corresponding smoothed points indicated by the red squares in Figure 5.

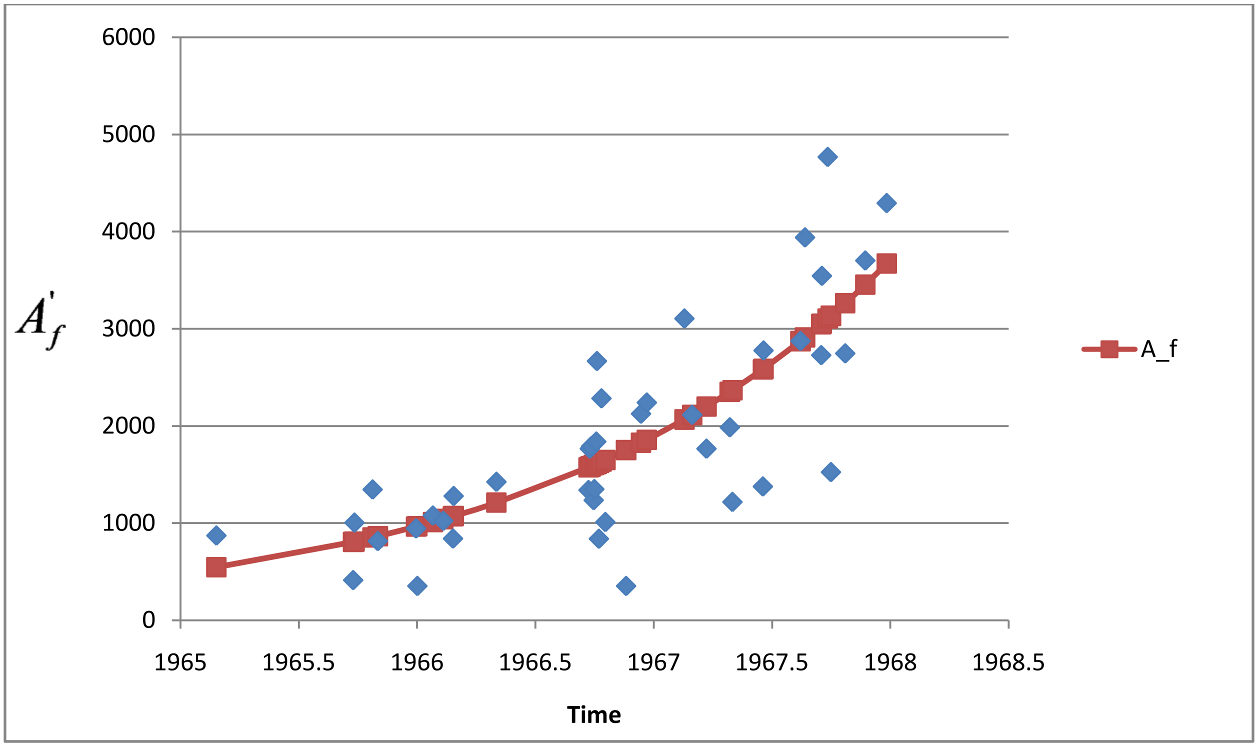

Fig. 5. A plot of A_f' vs. Time smoothed by an exponential function as represented by red squares.

The smoothing of the measured facular area measurements is necessary for the comparison with the corresponding RGO 13-month running mean smoothed sunspot areas, a fundamental step on our analysis. Both datasets need to be smoothed to remove any effects due to the substantial difference in mean lifetime of spots and faculae. A plot of smoothed sunspot area versus smoothed facular area ≤ 1500 millionths of a solar hemisphere was then constructed and is shown in figure 6.

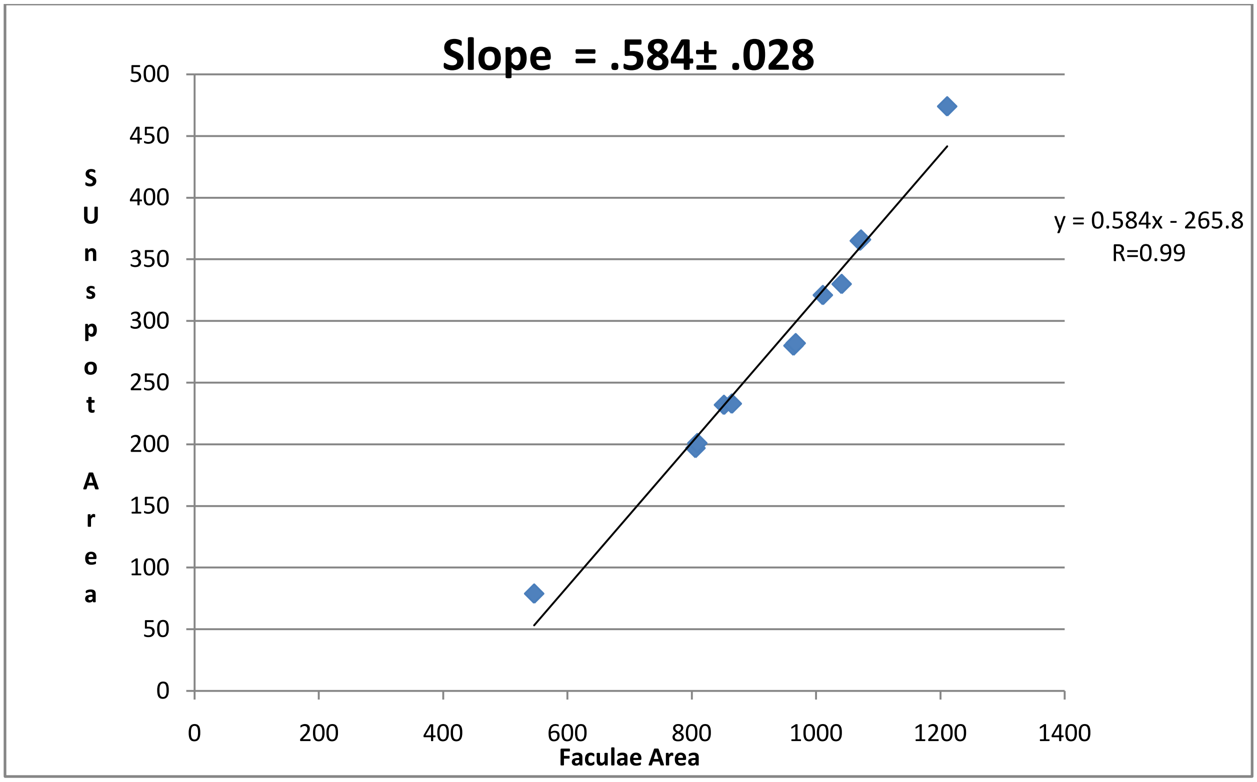

Fig. 6. A plot of smoothed sunspot area vs. smoothed faculae area ≤ 1500 millionths of a solar hemisphere, slope is 0.584 and correlation of coefficient is approximately 0.99

This plot shows a strong linear relationship between smoothed sunspot area and smoothed faculae area, with a correlation coefficient of approximately 0.99 and slope of 0.584. The faculae area ≤ 1500 millionths of a solar hemisphere is a parameter of the Brown and Evans Model (1980), shown in equation 3.

$$R_{max} = e^{\frac{2.23+m_{1500}}{0.60}} \qquad (3)$$

Where R_{max} is the maximum sunspot number and m_{1500} is the slope of the regression line from figure 6. When inputting the slope into equation 3 we obtain a maximum sunspot number of approximately 109 with a 1-σ range of [103,114], from data taken from 1965 to 1966. The actual maximum sunspot number recorded for solar cycle 20 was 106 in 1969.

4. Conclusion

Our results show that we were able to make a very strong prediction of the maximum sunspot number for solar cycle 20 with a lead time of 3 years based on the Brown and Evans model (1980). However, more analysis still must be done to see if these results are consistent. Further research will involve using these techniques to make predictions for other past solar cycles and subsequent cycles to come.

Acknowledgments

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