SOLAR CYCLE DEPENDENT VARIATION OF SOLAR GRANULATION

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\section*{ABSTRACT}

In this paper we study the problem of the variation of solar granulation with the solar activity cycle. For that purpose a homogeneous dataset consisting of photographically taken white light images was used. The data were all obtained with the same instrument at the same observatory (Pic du Midi). Since the variations are expected to be small, a careful study was done to measure the influence of seeing, selection of a specific area and evolution of the granular structure on the results.

Key words: Sun; solar cycle; granulation.

\section*{1. INTRODUCTION}

The solar granulation is the visible manifestation of convective overshooting in the solar interior that starts about 200 000 km below the solar surface. A review about solar granulation was given by Muller (1999).

The Sun is an active star with an activity cycle of about 11 years. Since the process of energy transport must be related with the overall solar energy output it is reasonable to suspect that there must be a relation between key parameters of solar granulation, such as their size, evolution etc. and the solar activity cycle. However, such a relation must be of a very small order and not very much pronounced since it has not been confirmed definitely so far.

Attempts to measure a variation of solar granulation size with activity cycle have been made by Macris and Rösch (1983) and Macris et al. (1988). They claim to have found a variation of about 10\%. The granules were measured visually and the quality of the data was not uniform. The visual identification may not be objective enough.

In this paper we study the variation of solar granulation size using a homogeneous dataset that was obtained at the Pic du Midi observatory by one of us (R.M.) under excellent seeing conditions.

\section*{2. DATA}

Images of the solar granulation were obtained quite regularly with the same optical setup between 1978 and 1995. Here we present preliminary results for the period June 1978 to September 1988 thus comprising the rise to solar activity maximum that occurred around 1980 and the decrease of activity.

During that period there were no changes in the optical setup of the telescope. The image scale was controlled and measured for each set of data. The instrument used was a 50cm refractor with a focal length of 6500 mm. A 100 Å passband filter centered at λ5750 Å was used.

The size of granular structures can be measured in different ways. This was discussed e.g. by Hirzberger et al. (1999). In this paper we use the simple method of the autocorrelation function because its width is directly related to the scale of the granulation and it is an objective method which does not require any pre-processing of the images that may influence the results. This function was computed at different lags.

\section*{3. ANALYSIS OF ERROR SOURCES}

In this chapter we study the influence of varying atmospheric conditions (seeing), granular evolution and selection of datasets on the behavior of the autocorrelation function which will be used as a simple measure for the size of granular structures.

For these tests different datasets were used:

- burst of about 50 images; the images were taken on Aug., 28, 1985. The time lag between two successive images was 1/24 s. The pictures were digitized at Paris with the MAMA machine and the scale was 0.103'' per pixel. In total a field of 600 × 600 pixels was used. This corresponds to a field of about 60'' × 60''. Therefore, the field roughly contains 1500 granules. We will refer to this time series as burst.
a three hours time series obtained at the Pic du Midi observatory on Sep. 20, 1988. The series was taken photographically and digitized at Lockheed. 1 pixel corresponds to 0.13” The field contained 416×340 pixel, thus a field of 55” × 48” was investigated. From this time series two portions were analyzed: a) a sequence of 40 images with excellent seeing, b) a sequence of 40 image with varying seeing conditions (as were noticed by the observer).

The granulation size was defined by measuring the autocorrelation function (acf) at various values for the ordinate. At lag 0 the acf has the value 1 and we searched for the corresponding value on the x-axis (which is given by the lag) for y=0.6, 0.4 and 0.2.

To have a measure for the varying seeing conditions, the rms contrast of the images was calculated and plotted.

3.1. Influence of seeing

Using a burst of images the influence of seeing on the behavior of the ACF can be studied. The burst of images was taken within a very short time interval so that evolutionary effects can be excluded.

Using the burst data the rms variation of the acf was found to be in the order of less than 2%.

The three examples studied show the following trends:

- The acf clearly correlates with the image quality. The image quality was measured by means of the contrast.
- Higher contrast means lower values for the acf.
- If we want to take the acf as a measure for granular structures than we must take into account that only the best images should be selected in order to minimize the effect of varying seeing conditions. This is demonstrated e.g. in the La Palma data (they where obtained by P.N. Brandt and G. Simon and consisted of a 9 h time series): when using only data with rms > 0.72 than the slope of the fit rms-acf becomes negligible, thus the acf does not depend on the rms values. This is valid for more than 3/4 of the data. Even in the case of bad seeing (see Fig. 1) the slope of the fit rms-acf for rms > 0.45 becomes negligible.

The influence of varying seeing conditions on the acf can be summarized in Table 1.

We therefore conclude that for the further study of acf variations it is important to a) calculate the rms variation of intensity and then b) select cases where the rms is in the highest e.g. 20% range to be sure that seeing influences are small. This is the case with the granulation images we have selected for the present investigation.

![Figure 1. La Palma data: ACF for three different cases: a) at y=0.2, b) at y=0.4 and c) at y=0.6.](image1)

![Figure 2. La Palma data: Standarddeviation of contrast and ACF.](image2)

3.2. Influence of granular evolution

In this section we study the influence of the evolution of a granular/intergranular field on the behavior of the acf. Therefore, we used data that were completely free of any seeing influences. These data were derived from a simulation of solar granulation as it was made by Nordlund. The total size of the field was 315 × 315 pixels and one pixel corresponds to 0.1”. Thus the total field covers 31.5” × 31.5”
Table 1. Influence of seeing on the acf

<table>
<thead>
<tr>
<th>time series</th>
<th>acf max value</th>
<th>acf min value</th>
<th>acf (mean value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>burst (50 images) non filt.</td>
<td>1.13</td>
<td>0.95</td>
<td>1.03</td>
</tr>
<tr>
<td>burst filtered</td>
<td>0.94</td>
<td>0.72</td>
<td>0.88</td>
</tr>
<tr>
<td>3h series bad (350...390)</td>
<td>1.36</td>
<td>0.88</td>
<td>1.03</td>
</tr>
<tr>
<td>3h series good (170...210)</td>
<td>1.17</td>
<td>0.88</td>
<td>0.96</td>
</tr>
<tr>
<td>La Palma</td>
<td>0.70</td>
<td>0.62</td>
<td>0.65</td>
</tr>
</tbody>
</table>

which is slightly less than in the case of the data discussed above. The step width between the individual images was about 21 s.

The results are given in Fig. 3. The standard deviation (rms) contrast was calculated and the values were about 15% which is typical for simulations.

Figure 3. Standard deviation of contrast and acf for simulated data

In this case the rms variation is due to evolutionary effects in the field. The effects are large at the beginning (image 0...20) and near the end of the sequence (image 80...90). It is clear from this that evolutionary effects influence the acf and that several images should be taken for an analysis of the acf.

3.3. Influence of the size of field selected

In this section we study the dependence of the acf on the size of the selected field. For this investigation again the simulation data were used. The acf was calculated for 4 cases:

- full image (315 × 315) (this corresponds to factor 0 in Fig. 4)
- image reduced to (265 × 265) (this corresponds to factor 1 in Fig. 4)
- image reduced to (215 × 215) (this corresponds to factor 2 in Fig. 4)
- image reduced to (165 × 165) (this corresponds to factor 3 in Fig. 4)

Figure 4. Standard deviation of contrast and acf for simulated data for different reduction of the original image.

3.4. Other influences

It turns out that the acf strongly depends also on the field selected. In the data of 1985 there are regions of abnormal granulation. These have to be avoided, otherwise the acf values would become too small.

4. RESULTS

In Fig. 5 the resulting values for the acf are given at \( y = 0.2 \) and \( y = 0.4 \) for data in the time interval 1979-1988. This covers nearly one full solar cycle. We can see that: The Variation of the autocorrelation function with solar activity is not much pronounced. A slight trend is visible: maybe a small decrease of the acf with increasing Wolf number, i.e. the structures become larger - this is in contradiction with previous works. A maximum around Wolf number 100 can be found but there are too few data to make a definite conclusion. The Variation of solar granulation found is not much larger than a variation due to granulation evolution and other effects. It is below 4% and
thus clearly below the 10% that was claimed to have been found.

From the point of view of the theory of solar convection a value of 10% for the variation of granulation size would imply a strong variation of the scale height of the appropriate parameters since the scale height is related to the size of the elements. This is also very difficult to explain and our results seem to better fit the theory.

Figure 5. Variation of the autocorrelation function during a solar cycle.

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