The Solar Convection over a Solar Cycle

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Abstract. We study the variation of granular size and contrast over a solar activity cycle. Two different homogeneous data samples were used, from Pic du Midi and from Hinode. The results do not confirm previous values cited in the literature. From the Hinode data the granulation seems to be constant, the trend found may be of instrumental degradation. We try to explain the result by other observations like the total solar irradiance variation. This variation was small over the past five years and may explain why in the case of Hinode data no significant variations were found.

1. Introduction

The energy is transported to the solar surface by convection which starts at a depth of about 200,000 km below the solar surface. In the photosphere, convective motions can be observed as granulation. In bright hotter granules matter is moving upwards, in the darker intergranular lanes it sinks down again after cooling.

The properties of solar granulation are well known. The average size is in the range of 1000 km, the lifetime about 7-10 min. However, it is difficult to determine these values exactly, for details see the review by Nordlund et al. (2009).

In this paper we address the question whether solar convection remains the same over an activity cycle or it could change. Solar activity is connected to magnetic flux emergence. Simulations made by Cattaneo et al. (2003) and Vögler (2005) showed that convective motions and the granulation pattern changes. Foukal (2010) investigated irradiance variations in cool stars. His study suggests that the structure of emerging magnetic fields shifts toward lower spatial frequencies with increasing activity. Magnetic self-organization in the deep convection zone determines the topology and evolution of these surface fields, which in turn affects the irradiance as was pointed out by Miesch (2010).

On larger scales supergranulation has to be considered: magnetic elements become distributed in lanes that form a network which affects the radiative energy of the upward plasma in the chromosphere and transition region. A difference in size of 0.5 Mm was found when comparing the minima of cycle 22/23 and cycle 23/24 by McIntosh et al. (2011).

A model of vertical flux tubes predominates in the intergranular lanes and reduces the size of granulation. Such a change could have different manifestations: shape, size, dynamics. The determination of such a change requires high resolution observations.
over at least one solar activity cycle. An early attempt was made by Macris et al. (1984). They used data from the Pic du Midi observatory starting in 1966. The photographic data were reduced by counting granules in a definite field or by calculating the center-to-center distances. They claimed to have found a substantial change of these parameters during a solar activity cycle. In a $10'' \times 10''$ field the number of granules was around 35 during minimum and 45 during maximum.

The drawback of this investigation is that it was done using different data sets (for example the refractor lens changed from 38 cm to 50 cm). So it is difficult to calibrate them accurately. The problem using different data sets for high precision measurements of solar parameters is e.g. very well known when calibrating solar irradiance measurements.

In this investigation we try to avoid the above mentioned problem and used two homogeneous data sets: (a) high resolution observations from Pic du Midi and (b) Hinode observations. It will be shown that the results are ambiguous yet, but it becomes evident that there exists no 10% variation that has been claimed.

2. Data

The study of the change of solar granulation with solar activity cycle requires excellent homogeneous data series covering at least one full solar cycle. We have used two different data series, one from the ground based Pic du Midi observatory and one from the Hinode satellite mission.

2.1. Pic du Midi Data

At the Pic du Midi observatory solar high resolution observations have been made for a long time and we analyzed a data set starting in 1978 ending in 1993. The data were taken photographically with a 50 cm telescope. The field of view was about $70'' \times 70''$. During the above mentioned period, the instrumental setup remained unchanged. The data were selected for high contrast, and they were taken near the solar disk center. After the selection process the data were calibrated and digitized which is unfortunately a source of error.

2.2. Hinode data

The Japanese/US Hinode mission provides data of high resolution in different wavelengths. We have used the data obtained in the blue continuum. The observations started in December 2006. The size of the digitally recorded frame was at the beginning $4096 \times 2048$ pixel and was later binned by a factor of two because of telemetry problems. Thus we have binned all data to the value of $2048 \times 1024$ pixels.

3. Results

3.1. Pic du Midi Data

The results of the Pic du Midi data have been already published by Muller et al. (2007). The data were taken with the 50 cm refractor between 1978 and 1993 under excellent seeing conditions. The optical set was kept the same during that time consisting of an interferential filter (6 nm wide, centered at 575 nm) and a reimaging lens. However the
data set is not perfectly homogeneous, the scale of the images varied between 0’08 and 0’10 per pixel, the film calibration is inaccurate. The images were digitized and only quiet sun images near the solar disk center were selected. The image analysis consisted of an autocorrelation analysis contrast variation study and a power spectrum analysis. The main results from this study were:

- No significant variation in granulation cell size was found.
- A variation of granular contrast was found. For solar activity maximum the contrast is larger than for solar minima.
- An exact quantification of the amplitude of the variation is uncertain for such data sets because of uncertainties due to the calibration procedure.
- The variation in contrast seems to be about 15%.

3.2. Hinode Data

For the analysis of we used data taken with the blue broadband filter of the Hinode synoptic program taken with the SOT (Solar Optical Telescope). The filter is centered at 450.4 nm, the width of the filter is 0.4 nm. For all analyzed images the pixel size is 0’11 and the field of view is 228’’ × 114’’. All images have been calibrated with the standard solar reduction software distributed under SSWIDL, which corrects cosmic rays, bad/defect pixels, readout errors, the dark current and the flat field. A careful inspection of the images showed that some of them were blurred. We selected images that were taken near solar disk center and where no pores or spots were visible. The first image analyzed was from November 2006 which was definitely in the solar minimum phase, the last image analyzed was from the end of 2010 which was in the ascending phase of solar activity.

In Figure 1 we give an example of the variation of the number of detected granules in the whole field of view detected by an automated segmentation algorithm. The data shown here are not corrected for the varying Sun-Earth distance for illustration purposes. One sees that a possible effect of varying cell size that would lead to a higher counting number of detected elements is smaller than that variation. There is a slight tendency towards fewer detected elements with the onset of solar activity which means that the granules become slightly larger when solar activity increases.

From the images, the contrast and the size of the granulation was calculated. The size was determined by two methods (i) calculation of the inverse of the median wavenumber of the power spectrum in the granulation range (ii) from the autocorrelation function. The results showed:

- The root mean square of the fluctuation in contrast is 1% and the peak-to-peak amplitude is 4%.
- The fluctuations of the granulation scale are smaller, 0.6% and 2.3%, respectively.
- The granulation appears to be uniform around the equator.
- There is an overall trend of a slight decrease of contrast.
- There is a small increase of scale.
Figure 1. Number of detected granules in segmented images. The data series used here starts in Nov. 2006 and ends in summer 2009.

- The results maybe interpreted in the sense that both contrast decrease and scale increase, because of the overall trend and small values, maybe not of solar but of instrumental origin.

- During the time interval 2007-2009 solar activity slightly increased, however the maximum activity is expected for 2013/2014.

From Hinode G-band images we also calculated the number of bright points. This number showed a decrease with increasing solar activity.

4. Conclusions and outlook

We have used two very homogeneous data sets in order to test whether solar granulation changes or not. Certainly the Hinode data are more suitable since there are no disturbing atmospheric effects. We conclude that at the moment it seems that granulation scale and contrast is unchanged over an activity cycle. But it is also clear that further observations and longer time series are needed. Moreover, it would also be interesting to test whether the dynamics of granulation changes over a solar activity cycle, i.e. lifetime of granules etc. Since these effects are expected to be small, careful analysis is required. The upcoming large solar telescopes like ATST and EST will provide ideal tools for that.

Neglecting magnetic fields, convection can be described by the set of hydrodynamical equations where the velocity field, pressure gradient and density gradient drive the motions. It was found that magnetic fields near the vicinity of sunspots change the granulation structure and motions (abnormal granulation). Hanslmeier et al. (1991)
reported that both continuum intensity and velocity fluctuations are reduced in active regions on granular scales but not on sub granular scales. Thus there is an interaction between magnetic flux and granulation. Therefore we could expect to find a variation of granulation at small scales over a solar activity cycle.

A possible explanation of our negative results is the fact that the Total Solar Irradiance (TSI) variation, is lower around the last minimum than in the two preceding ones (1996, 1986). The variations during the two last solar cycles were larger than during the ascending phase of cycle 24:

- Variation 2006-2011: about 0.3 W/m².
- Variation Minimum cycle 23 - Maximum cycle 23: 1 W/m².
- Trend: there is a small increase of the TSI from the solar minimum 2009 to Febr. 2010, about 0.2 W/m².

These results are from Steinhilber (2010). If we expect a variation of up to 1 W/m² then the effects on solar granulation scale and contrast could be also stronger, so our observations will be extended to the next solar maximum in 2014 at least.

It should also be noted that there are two basic contributions to TSI variations. During high solar activity, the X-ray and extreme UV (EUV) dominate. This variation is driven by changes in large-scale coronal magnetic morphology. During low solar activity the TSI variation is dominated in the UV and IR radiance. This is driven by supergranular and granular length scales of emission in the transition region, chromosphere and photosphere as was stated by Fröhlich & Lean (2004). During solar maxima, where TSI variations can be as high as 0.1%, the heat flux due to solar granulation should be increased which can be found in Spruit (2000).

As it has been stated above, the new facilities ATST and EST would provide the best data for such studies. It would be sufficient to have the following data over at least one solar cycle: in the best case one time series of excellent seeing conditions every 2 to 3 months. The length of the time series should be about 1 h. With such data we will be able to study the variation of granulation size, contrast and dynamics.Since the shorter lifetime of satellite missions, ground based observations would be preferred.

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