Mem. S.A.It. Vol. 78, 71

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Space and time variation of the solar granulation

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Abstract. Granulation images, taken on film with the 50 cm refractor of the Pic du Midi Observatory between 1978 and 1993, have been analysed. The solar granulation appears to vary, both in space, along the solar equator, and in time, in phase with the activity cycle. Around the equator, the granulation scale varies with an amplitude as large as 15%; the contrast varies similarly: where the scale increases, the contrast increases too. Concerning the time variation, only a variation of the contrast is detected: it is smaller at periods of solar maxima. We cannot quantify the amplitude of the variation because of photometic uncertainties. We do not detect any variation of the scale of the granulation: it must be of much lower amplitude than the contrast variation.

Key words. Sun: granulation – Sun: activity cycle

1. Introduction

More than two decades ago, Macris & Rösch (1983) and a little later Macris et al. (1984) reported that the mean distance between granule centers decreases with increasing activity, with an amplitude as large as 10%. But the set of images was not homogeneous: they were taken at the Pic du Midi Observatory between 1966 and 1976, with two different refractors, 38 and 50 cm of diameter, at different wavelengths and under varying seeing conditions; in addition, one image, taken with the 60 cm Solar Tower Telescope at Sac Peak Observatory, was included. The decrease of granule size with increasing activity was confirmed later by Roudier (1986) and Muller (1988) who counted the number of granules per surface unit, on images of higher homogeneity, taken between 1973 and 1985 at the Pic du Midi Observatory. In all of these investigations, granules were identified visually, inducing uncertainties.

Here we present new results derived from the analysis of a much more homogeneous set of images, taken with the 50 cm refractor at the Pic du Midi Observatory between 1978 and 1993, under superb seeing conditions. All images are apparently free of any trace of seeing. The same, very simple, optical set up was used over the years; it consisted of a reimaging lens and of an interferential filter (6 nm wide centered at 575 nm). However, the data set is not perfectly homogeneous: the scale of the images is varying between 0”08 and 0”10 per pixel; the film calibration is unaccurate and is the main source of uncertainties for granulation

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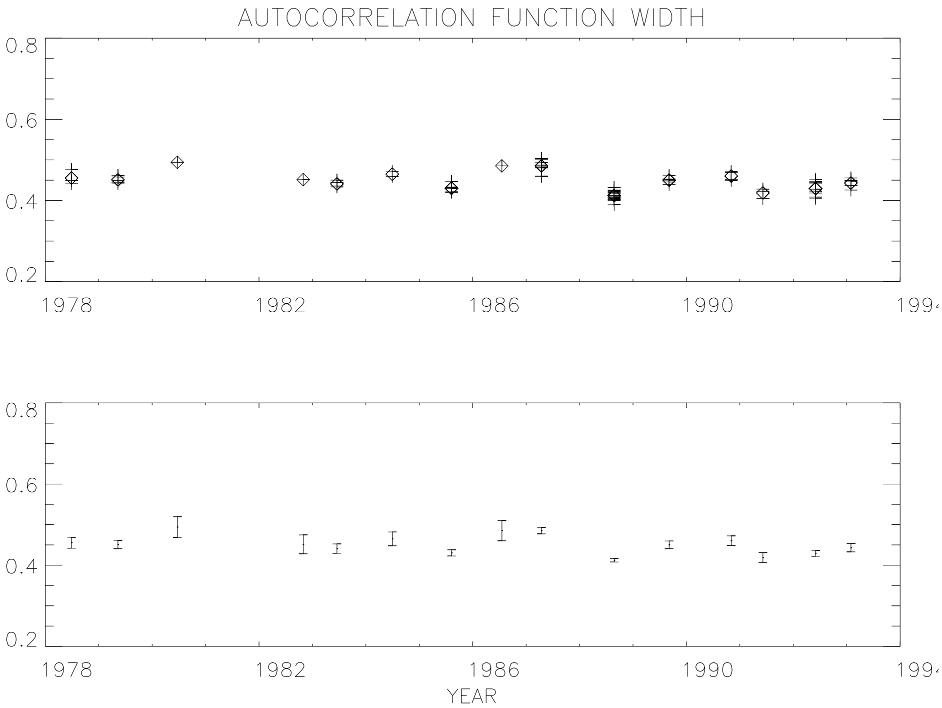

Fig. 1. Variation of the Autocorrelation Function Width (ACFW) at half maximum, of granulation images taken between 1978 and 1993; upper panel: each cross represents one image, field of view: 70" x 70"; lower panel: mean values and statistical error bars of each observation.

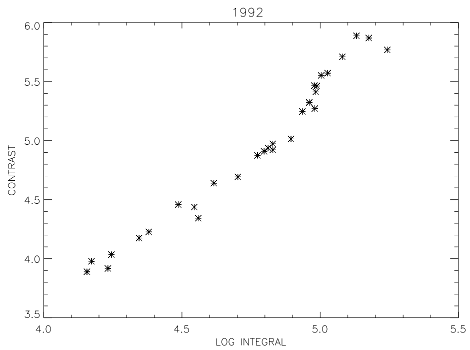

Fig. 2. Relation between the square root of the integral of the power spectra (contrast) of the images taken in 1992 and of the integral computed in logarithmic scale (log integral).

contrast measurements. Possible slight residual seeing differences among images proved to be negligible.

All images were taken at the disk centre or at close proximity, in order to avoid foreshortening effects. They either belong to time series taken at disk center or to sets of images taken around it. Absence of abnormal granulation in the white light images insures that they were taken in quiet sun areas, away from remnants of active regions and from active network. Inspection of associated G-band images, when available, confirms that the observed areas were very quiet.

2. Image processing

The images were digitized with the MAMA at the Observatoire de Paris. The philosophy adopted to process our particular set of images, was to use techniques which have a min-

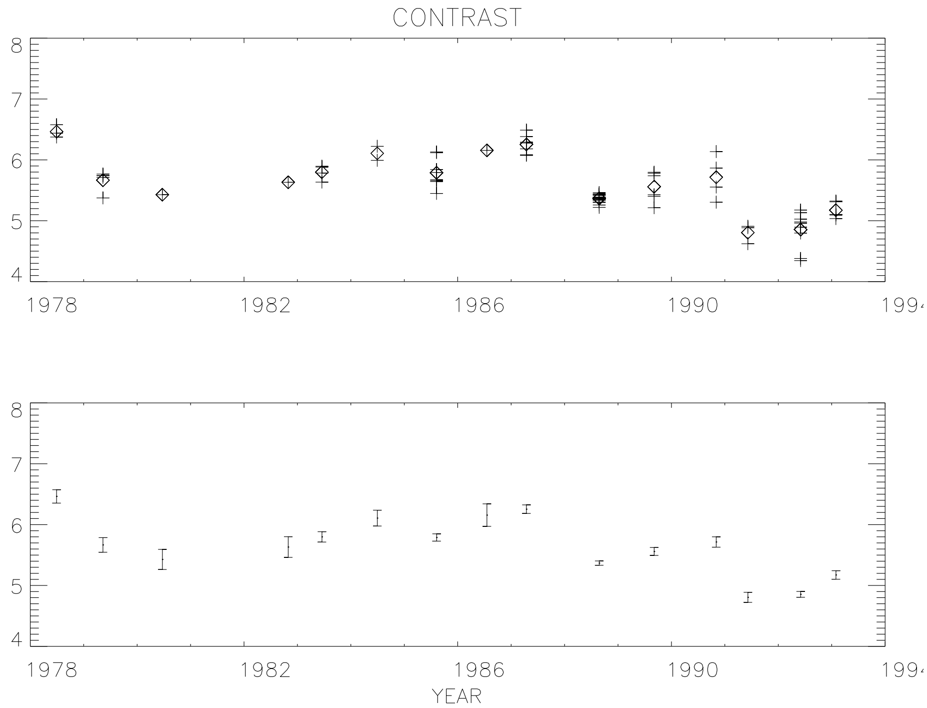

Fig. 3. Same as Fig.1, for the contrast (power spectrum integral in logarithmic scale, see the text).

imum effect on the results. That is why we used, as a first step, autocorrelation functions and power spectra to investigate the granulation scale and contrast variations. They are simple and robust statistical methods, which can be used directly on the images, without any pre-processing which could affect the results. More informations would be provided by granule size histograms derived from granule segmentation. But segmentation depends of several parameters (filter parameters, cut-off level), which are difficult to control and to keep constant for different images. However, it will be the next step of our investigation.

3. Results

3.1. Autocorrelation analysis

The width of the autocorrelation function at mid level (ACFW) is used as a measure of the granulation scale. Its variation between 1978 and 1993 is plotted in Fig. 1. Each cross in the upper panel is the ACFW of one image (field of view: 700 x 700 pixels, or about 70" x 70", depending of the image scale). The images which were taken on the same day or on a few consecutive days, belong to what we call an "observation". The diamonds represent the average ACFW of each observation. Several interesting points are noticeable in Fig. 1: 1) There is no variation related to the solar cycle. 2) In several observations, the dispersion is large, up to 10%; it is mainly due to the evolution of the granulation pattern in a 70" x 70" field of view; there is also a contribution when the images were taken at various positions around the disk centre. 3) There are large differences between average ACFWs: 15% between 1987 and 1988; 12% between 1988 and 1990, 10% between 1990 and 1991. These differences are much larger than the statistical error bars (Fig. 1, lower panel), simply computed from the maximum dispersion (10%) and the number of images in each observation. These

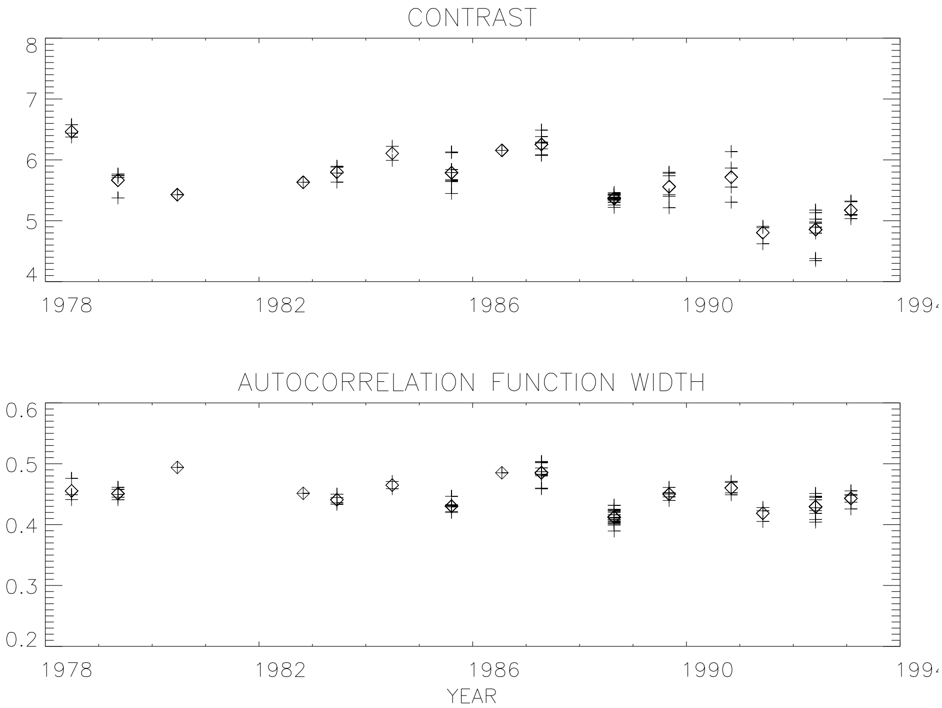

Fig. 4. Comparisaison of ACFW and contrast variations.

large differences are thus, probably, of solar origin. As the observations were taken at random relatively to the solar longitude, we conclude that they reflect a spatial variation of the granulation scale around the equator.

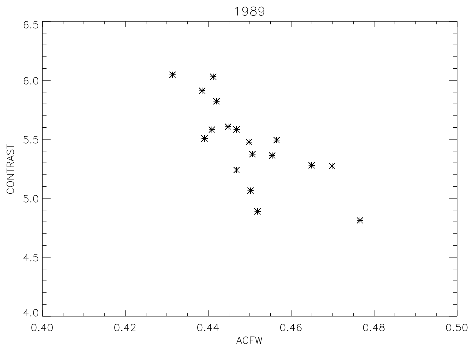

Fig. 5. Variation of the granulation contrast versus the granulation scale; exemple for the images taken on October 3, 1989.

One may have an idea of the period of the spatial variation, by looking at Fig. 1 in more details. In 1983 and in 1993, the images were taken over three and two consecutive days, respectively. The dispersions are small, indicating that the period is large than 25 degrees. In 1992, the images were taken on July 3 and on July 11. The difference of the mean ACFWs between these two days is 7.5%, larger than the error bars, and is thus significant. The separation between the two days is not clearly visible in Fig. 1, because the crosses belonging to the two days partly overlap (the two lower crosses belong to July 3, the remaining ones above, to July 11); but the separation is very clearly visible in the contrast variation in Fig. 3, upper panel. Between July 3 and 11, the Sun has rotated by 100 degrees. We conclude that the period of the longitudinal spatial variation of the scale of the granulation is about 100 degrees.

3.2. Power spectrum analysis

Power spectra are used to compute the root mean square of the granulation intensity fluctations, which is the square root of the power spectra integral. For simplicity we will call it "contrast". The problem is that the amplitude of the power spectra is related to the film calibrations, which are unaccurate. Consequently, our observations do not allow us to derive contrasts with a sufficient accuracy to expect to find a variation related to the solar cycle. Fortunately, the integration of the power spectra in logarithmic scale above the noise level, is independant of film calibration: when computed with different calibrations, the power spectra plotted in logarithmic scale, are just shifted compared to each other in the y-direction of the plot, without any deformation. For each observation, there is a very close linear relation between the contrast and the integral of the power spectrum computed in logarithmic scale (for simplicity, we will call it "log integral"). Consequently, log integral can be used as a proxy to investigate contrast variations (Fig. 2). The integration is made in the granulation range, between 0"5 (to remove the noise) and 3"5 (to remove large scale fluctuations, which are not of granular origin).

The variation of log integral (contrast proxy) for the period 1978 to 1993 is plotted in Fig. 3. A variation in phase with the solar cycle clearly appears: the contrast is smaller in the periods of sunspot maxima. Like for the ACFW, the dispersion of the granulation contrast is large in several observations, up to 12%. The difference of contrast between the maxima of activity in 1980 and 1991 and the minimum of 1986 is 12% and 18% respectively, significantly larger than the maximum observation dispersion (12%) and than the error bars (Fig. 3, lower panel). We conclude that the observed contrast variation in phase with the solar cycle is probably real.

Moreover, when one compares the variations of contrast and ACFW (Fig. 4), the trends over short periods are very similar: they both decrease between 1993 and 1991 and between 1990 and 1988; there are jumps between 1991 and 1990 and between 1988 and 1987; the trends are also nearly identical between 1987 and 1982. This means that when one compares the granulation at two different positions along the equator, where the granulation scale is larger, the contrast is larger too. Spatially, the scale and the contrast of the solar granulation vary in phase. The variation of the contrast plotted in Fig. 3 appears to be a combination of two components: a time variation in phase with the solar cycle superimposed to a spatial variation around the solar equator. Locally, the granulation pattern is constantly changing, but the relation between the scale and contrast variation is different to that of the spatial variation reported above: when the granulation ACFW increases, the contrast decreases (Fig. 5).

4. Conclusions

Analysing a set of granulation images obtained between 1978 and 1993, we find that the granulation pattern is varying, both in space, with a large period around the equator, and in time, nearly in phase with the solar cycle. The amplitude of the spatial variation is as large as 15%, and the scale and contrast vary in phase. The time variation is in phase with the activity cycle: it is weaker at periods of solar maxima. But because of large uncertainties of film calibrations, we cannot quantify the amplitude of the variation. On the other hand we don't see a corresponding cyclic variation of the granulation scale : it must be of much lower amplitude than that of the contrast variation.

The origin of the variation of the granulation properties, both spatial and temporal, could be the solar magnetism: local magnetic flux (network and intranetwork), the distance to active regions, the global magnetic field which may act on the convection zone. In a next investigation we will look at the G-Band images which were taken nearly simultaneously with the white-light images, in order to estimate the local magnetic flux; we will also look at the location of the observations relatively to the closest active regions.

The results presented here could imply that the physical properties in the top of the convection zone and in the photosphere are not uniform, at least around the equator.

In January 2005, we have started again, with the 50-cm refractor of the Pic du midi Observatory, a dedicated program of observations of the solar granulation, consisting of images taken in white-light and in the G-Band, in order to improve the homogeneity of the data and the photometric accuracy, the latter thanks to the CCD camera. Solar-B images will also be used between 2007 and 2010, i.e. from the current solar minimum to the next solar maximum. A guest investigator program has been proposed.

Acknowledgements. The authors aknowledge the support of the Austrian-French scientific exchange program 'Amadeus' (R.M. and A.H.) and the support of the Austrian Fonds zur Förderung der Wissenschaftlichen Forschung (A.H. and M.S.). Part of this work was done while A.H. was visiting the Midi Pyrénées Observatory and R.M. the Institüt für Geophysik, Astrophysik und Meteorologie, Universität Graz. R.M. acknowledges the technical staff of the Pic du Midi Observatory for a 20-year long support. All images were digitized with the Machine à Mesurer les Images Astronomiques (MAMA) at the Observatoire de Paris. A special thank is due to R. Chesnel who made the measurements very carefully.

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