SOLAR IRRADIANCE FLUCTUATIONS ON SHORT TIMESCALES

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ABSTRACT

Although solar irradiance variability at time-scales of days to the solar cycle has been well studied, comparatively little is known about the causes of such variations on shorter time-scales. We present an analysis that aims to distinguish between magnetic and convective causes. It suggests that on time-scales longer than 1–2 days magnetic structures are the dominant source while for time-scales shorter than a few hours convection appears to dominate. We also present a simple granulation model that includes the various paths of granule birth and death and compare its output with VIRGO data.

1. INTRODUCTION

The source of the variations in solar total and spectral irradiance has been the subject of considerable debate. Most of it has centred on time scales dictated by solar rotation, by the evolution of sunspots and active regions and by the solar cycle. The interest in these and even longer timescales is driven mainly by the fact that the variations are strongest at these timescales and are probably responsible for the influence of solar variability on climate. Irradiance variability on timescales shorter than a day, however, are less well studied, although this variability is the main source of the noise background underlying the p-mode peaks [e.g. 1]. More recently, noise at these time scales has become important for the search for extrasolar terrestrial planets through the detection of transits [2, 3, 4, 5, 6]. Such research has gained in importance due to the planned space missions COROT and Eddington.

The cause of the irradiance variations on timescales between a week and the solar cycle has been clearly shown to be the evolution of the Sun's magnetic field, with the darkening due to sunspots dominating on time scales of weeks, while the brightening due to faculae and in particular the network dominates over the solar cycle [7] [cf. 8, 9]. For shorter time scales the source of the variability is still rather unclear, with convection usually being cited as the main cause. Thus Fröhlich et al. [10] attribute different time scales, minutes, hours and days to granulation, mesogranulation and supergranulation. Harvey [1] was the first to set up a model to describe the background noise affecting helioseismology. Making clever use of the relation between the autocovariance of the time evolution and the power spectrum he produced a spectrum of the solar noise without having to explicitely model the individual solar features and their evolution.

Later, the noise has been modelled by Anderson et al. [11] and Rabello Soares [12] using basically a combination of granulation, mesogranulation and supergranulation (like [1]). These computations are based on explicit models of the different types of convective features. With a combination of 2 convective and 1 magnetic (just a power law) spectra the observed solar power spectrum can be well reproduced. Thus this approach has yielded good results. This raises the question: why do we repeat this exercise i.e. model anew the short term solar variability?

One reason is that the previously taken approach does not clearly distinguish between magnetic and convective sources of the variability. For example, the component termed 'supergranulation' may mainly reflect the evolution of the magnetic network. This becomes an important issue when scaling to other stars, since magnetic and convective variability should scale in very different ways with stellar parameters such as effective temperature, gravitational acceleration and rotation rate. Other problems are raised by the fact that supergranulation does not appear to show any intrinsic brightness contrast once magnetic fields are blanked out [13]. Mesogranular structure becomes visible when considering the spatial distribution of, e.g., exploding granules [14, 15], and it is unclear if they show any intrinsic contrast, while supergranules are prominent in intensity images mainly due to the excess brightness of magnetic elements.

Here we therefore describe an attempt at detailed modelling that clearly separates magnetic and convective effects. Thus we consider only granules and magnetic effects, leaving aside meso- and supergranules. This is still work in progress and the current results are still incomplete and very preliminary.

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Here we only discuss the influence of granulation since the influence of the evolution of the surface magnetic field, which has been modelled with considerable precision using magnetograms on time scales from days to the solar cycle [16, 7], is not reliably known as yet on times shorter than a day.

2. DATA ANALYSIS

Before carrying out the modelling we attempted to identify the frequency or period at which magnetic and convective contributions to irradiance variations are roughly equal. With this aim we cut the VIRGO total irradiance and 3 colour channel time series into two parts, one representing low solar activity, the second high activity. Detrended data are employed to compute the power spectra, mainly in order to remove the large trends introduced by degradation of the Sun-Photometers producing the colour channels. For our purposes detrending has little effect, since it affects mainly very low frequencies. We treated the numerous gaps in the original 1-minute sampled data by linearly interpolating across them. This is expected to influence the results mainly at the high frequencies, since most gaps are only a few minutes long. A similar analysis has been described by Fröhlich [18] and a figure of the power spectrum is given by him.

In order to better compare the power at high and low activity we plot in Figure 1 histograms of power centred at frequencies 1μHz, 10μHz and 100μHz, as well as the power averaged over these histograms. Clearly, at low frequencies there is considerably more power at solar activity maximum, while at higher frequencies it is difficult to distinguish between the two times.

These results are basically confirmed by a wavelet analysis using Morlet wavelets. A global power spectrum looks rather similar to the Fourier power spectrum, except that fluctuations are much smaller, which is due to the smoothing that Morlet wavelets automatically introduce, in particular when a low spectral resolution is chosen. Hence it is not necessary to compare histograms, but the power obtained at a frequency at activity maximum and minimum can be directly compared. The ratio of the wavelet power spectra is plotted in Figure 2. Obviously for periods longer than 1–2 days the power is considerably higher at activity maximum. At shorter wavelengths the situation is somewhat less clear. The ratio of wavelet power of total irradiance basically drops from a large value (over 100 at frequencies below 1μHz) to unit. In the 3 colour channels the ratio actually drops well below unity, although it is unclear if this is a real effect or an instrumental artifact. These results support the conclusions drawn from the Fourier analysis.

This may indicate that the irradiance fluctuations at time scales of between an hour and a day are

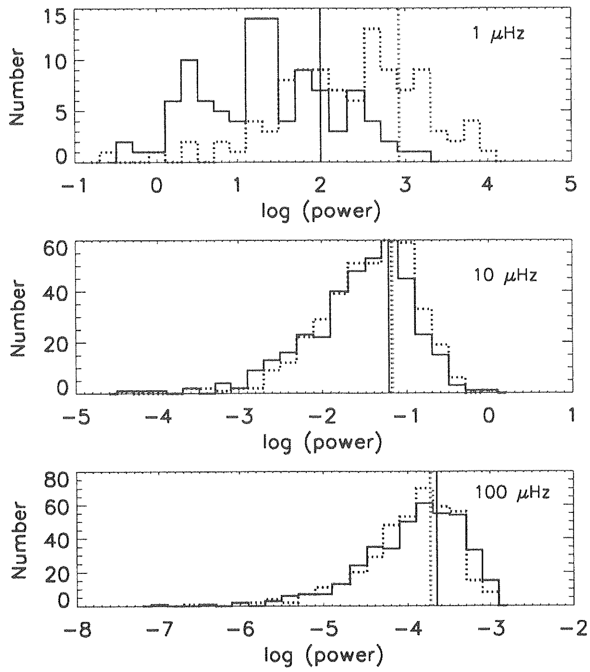

Figure 1. Histograms of power in the VIRGO total irradiance at different frequencies (indicated in each frame). Dotted: for solar activity maximum; solid: activity minimum. The vertical straight lines are the averages over the histograms.

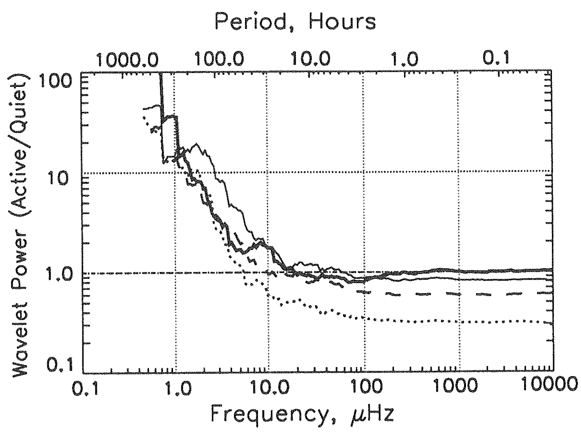

Figure 2. Ratio of wavelet global power spectra at activity maximum to the corresponding spectra at minimum. The curves represent total irradiance (thick solid line) and the 3 colour channels of VIRGO.

caused by both surface magnetic features and convection, at longer time scales the magnetic field dominates. Whether convection dominates at shorter timescales depends on whether the magnetic field in the quiet Sun (quiet magnetic network), which changes only slightly over the solar cycle, is an important contributor to irradiance. This can currently not be determined due to a lack of data (MDI has to our knowledge not sampled magnetograms at a sufficiently high rate for a sufficiently long interval).

3. MODEL OF IRRADIANCE VARIATIONS CAUSED BY GRANULATION

The basic assumption underlying the model is that the total contribution to irradiance from convection is due to the granulation. Traditionally, mesogranulation and in particular supergranulation are also included. Here we take the approach that we first compute models based only on the granulation and at a later stage test this assumption by comparing with observational data. We divide the solar surface into granules and intergranular lanes. For simplicity we consider each granule and the lanes surrounding it to have uniform brightness. The granules have different sizes, while the lanes always have the same width, their length being given by the fact that each granule is surrounded by a lane (with half of the thickness of the lane being attributed to "its granule"). For the ratio of granular to intergranular area we obtain an average value of roughly 0.7:0.3. The granules have a fixed lifetime distribution, with a given granule being attributed a random lifetime from within the distribution. The adopted distribution closely follows the exponential fit to the observations made by Hirzberger et al. [17], as can be judged from Figure 3, which shows the distribution obtained by Hirzberger (dashed curve) and the adopted distribution (solid histogram). Similarly, the adopted size distribution is similar to the distribution deduced from observations by Roudier and Muller [15]; see Figure 4. Two further free parameters are the total number of granules, N_{tot}, present on the solar surface at any given time and the brightness contrast between granule and intergranular lane. These parameters are uncritical in the sense that they only represent factors that multiply the resulting brightness fluctuations without otherwise changing their characteristics (i.e. in a log-log plot they simply move the irradiance power spectrum up or down, without affecting its slope or shape).

The remaining part of the model is a description of the evolution of each granule. We allow for different forms of granule birth: by splitting of a mature granule two new granules are formed, while new granules can also simply emerge from the background. Similarly, granules can die by two different processes, either by splitting or by dissolving. After birth the evolution of a granule is basically determined by the form of death assigned to it (this assignment is made randomly, with a weighting given by the granule size: the larger a granule the more likely it is to end by splitting). The splitters grow continuously after birth, whereas the dissolvers continuously get smaller. We impose no correlation between size at birth and lifetime. The evolutionary scenario described above is based on the results of numerical simulations [e.g. 14] ameliorated by insights gained from observations.

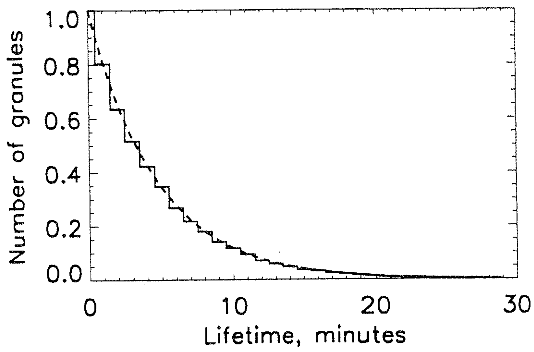

Figure 3. Normalized distribution of granule lifetimes. Dashed line: observed distribution; solid histogram: distribution adopted for the model.

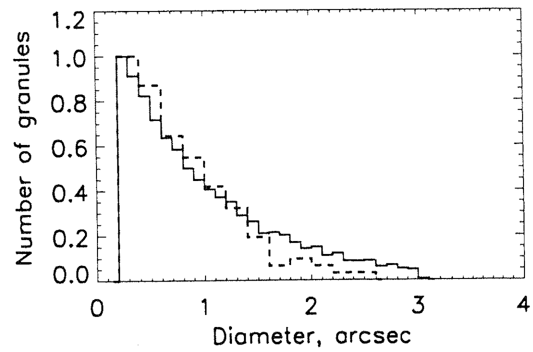

Figure 4. Normalized distribution of granule sizes. Dashed histogram: observed distribution; solid histogram: distribution adopted for the model.

4. PRELIMINARY MODEL RESULTS

In Figure 5 we compare the output of the model (upper curve) with the VIRGO data (lower curve). Note that the data have not been completely cleaned, which explains the spikes and parts of the differences to the power spectrum shown by Fröhlich [18]. Also plotted is the power spectrum resulting from the granulation model (upper curve; shifted for better visibility). At short time scales the 2 curves run roughly parallel to each other, around 1 hour the model curve has a distinct knee, while the data show a less distinct knee around 1/2 hour. Longward of the knee in the model the modelled power spectrum is flatter than the observed one.

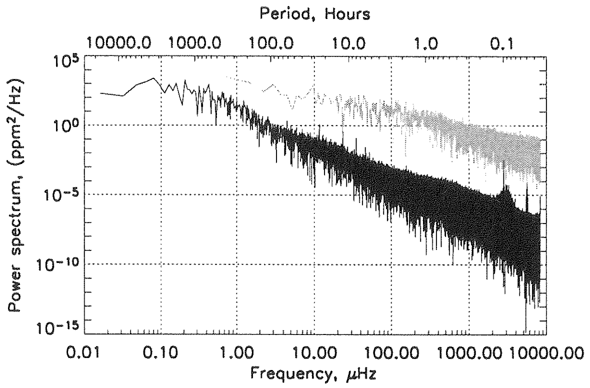

Figure 5. Comparison of preliminary model results (upper curve) with the power spectrum of VIRGO data (lower curve). The model curve has been offset vertically for greater clarity.

5. CONCLUSIONS

We have presented a simple model of the ensemble of granules on the solar surface. As a preliminary result we find that the model roughly reproduces the power spectrum of VIRGO data at time scales of less than 1/2 hour to 1 hour. On time scales longer than roughly a day we know that the magnetic field dominates [7, 19]. An open question is the source of irradiance variability at intermediate time scales. It is unclear whether mesogranulation is needed or if the combination of granulation and the magnetic field is sufficient. Together with further improvements to the granulation model this will be the main next step of our efforts. As a longer term aim we intend to extrapolate from the Sun to other stars.

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