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3-minute oscillations at wavelength 1.76 cm in 1992–2006
(Research Note)

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ABSTRACT

Context. We discuss variations of polarized radio emission using the correlation data obtained with the Nobeyama Radioheliograph at 1.76 cm wavelength. We focus on the radio 3-min oscillations.
Aims. We consider the daily averaged correlation data with right and the left hand circular polarizations in order to study how the power spectrum and the basic periods of the 3-min oscillations changed during 1992–2006.
Methods. We use spectral analysis to obtain the power spectrum of oscillations, excluding the solar flares.
Results. It was found that oscillations with a period of about 3 min occur during all phases of the solar activity cycle when at least one sunspot is present on the solar disk, and that there is a linear correlation between the strength of the 3-min oscillations and the monthly mean of the sunspot areas. The basic period of these oscillations changes, beginning from 150–160 s to 170–180 s with the level of solar activity. Also, we found that there is a linear correlation between the basic period and the monthly mean of the sunspot areas.

Key words. Sun: radio radiation – Sun: oscillations

1. Introduction

Investigations of oscillations play an important role in modern physics of the Sun. Generally, investigations have considered the active regions, such as sunspots, since periodic oscillations appear more clearly in their emission. Presently, observations of the oscillations are possible in different spectral regions, such as optical, UV-EUV, X-ray and radio. Recent studies have found that oscillations can be observed above the sunspots at different heights in the solar atmosphere (Brynildsen et al. 2004). The amplitude of the oscillations above the sunspots changes considerably with height, culminating in the transition region or in the low corona (O'Shea et al. 2003). Centimeter radio emission is generated from these regions. Three-minute oscillations play an important role among oscillations registered in the emission of active regions. In radio emission, the 3-min oscillations are more clearly detected in polarization (Abramenko & Tsvetkov 1985; Gelfreikh et al. 1999; Shibasaki 2001).

Magnetic fields of the active regions play an important role in the oscillations of the polarized radio emission with a period about 3 min (Abramenko & Tsvetkov 1985; Gelfreikh et al. 1999). Also, it has been shown (Shibasaki 2001; Nindos et al. 2002) that the magnetic field strength of these active regions could be above 2000 Gauss.

Modern data from the radio telescopes enable us to study the radio oscillations of the Sun in time intervals comparable with the whole solar cycle using homogeneous series of data (Tlatov & Riehokainen 2004). In this work we study the properties of the 3-min oscillations and their variations with the solar cycle.

2. Observations

In this work we used daily averaged correlation data (visibility amplitudes averaged over the antenna pairs, after removing short baseline pairs) obtained with the Nobeyama Radioheliograph (NoRH) at wavelength 1.76 cm. Antenna pairs whose baseline length is shorter than 24 m are excluded. In this case sources smaller than 20 arc s are sensitive to the correlation plot. The NoRH has been taking radio images of the Sun since 1992. The NoRH is a radio interferometer dedicated to solar observations, consisting of an array of 84 antennas with 80 cm diameter to cover the full solar disk and to synthesize radio images with high cadence and high dynamic range. The averaged correlation data contain the left (LCP) and the right (RCP) circular polarization components at 17 GHz with 1-s time resolution for each day and these data can be used for the study of oscillations as was shown by Shibasaki (2001). The total number of data points for each day is about 28 000–29 000, corresponding to approximately 8 h of observations.

3. Method

In our previous work we have found that 3-min oscillations are more clearly detected in the difference between LCP and RCP (Tlatov & Riehokainen 2004). In this work we consider the variation of the properties of the 3-min oscillations during the solar cycle.

Spectral analysis was applied to the daily radio polarization data, separately for each data set. Thus for each day of observations we obtained a power spectrum of oscillations. The procedure consisted of the following steps. Flare processes have much higher intensity than the intensity from the quiet Sun. For this reason, the data were preprocessed in order to exclude the records that have solar flares. For that, we considered the absolute values of correlation coefficients for the difference between the left and the right hand polarization. If the values of these coefficients were less or equal to 0.0002 (threshold value), we took them into consideration. Values above 0.0002 (in this case the solar flares have dramatic effect on the record of the correlation coefficient) were replaced by zero. The value of this parameter was obtained empirically from the correlation plots similar to the plot showed in Figs. 1 and 3 from (Shibasaki 2001). For an estimation of the spectrum power density (*SPD*) we used the fast Fourier transform (FFT) method with the Hamming window

$$SPD_k = \sqrt{S_k^2 + C_k^2}$$

where

$$C_k = \frac{a_k N \Delta t}{2} = \Delta t \sum_{i=0}^{N-1} y_i \cos(2\pi k i/N)$$

$$S_k = \frac{a_k N \Delta t}{2} = \Delta t \sum_{i=0}^{N-1} y_i \sin(2\pi k i/N)$$

N is the width of the Hamming window, $\Delta t = 1$, $y_i = LCP - RCP$ and k corresponds to the selected frequency. For time intervals (months or years) longer than the time interval of the sample we used the averaged power spectrum index $\overline{SPD}_k = 1/l \sum SPD_k$ where l is the number of samples.

In some cases we used an *SSPD* index in which we summed the spectral power density SPD_k of the 3-min oscillations for an interval of periods $T_1 - T_2$

$$SSPD = \sum_{k=k_1}^{k_2} SPD_k$$

where indices k_1 and k_2 correspond to T_1 and T_2.

Also we tried to use a discrete Wavelet method with Morlet functions in our work. For the separate days the *SSPD* index calculated using Wavelet method did not show any advantages in comparison to the FFT.

4. Results

The data from the Nobeyama Radioheliograph allow us to make an analysis of the different components of the solar radio emission. Figure 1 shows a record of polarized radio emission on 07.04.2004.

Using the shifted Hamming windows, we found that the intensity of the 3-min oscillations varies during the day. The number of data points for the spectral window was 2048 (or about 34 min). This window was shifted by 2 min along the series during the day to estimate the spectral power variation of the 3-min oscillations. Figure 2 shows a variation of the *SSPD* index with a typical period of 1.0–1.5 h. Unfortunately, the origin of this period is not clear to us.

Figures 3 and 4 show the daily averaged power spectrum $\overline{SPD}$ in 1992–1996 and in 1997–2006 for the difference between the left and the right hand circular polarizations. The summation, presented in these figures, was made with original *SPD* for each day from the corresponding interval of time. The daily power spectra were not normalized, but the flare removing process can be considered as a normalization of the initial data for

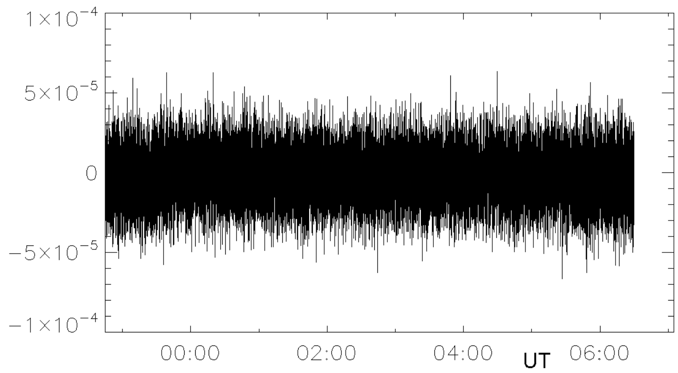

Fig. 1. Correlation plot for the difference between the left and the right polarized radio emission obtained on 07.04.2004.

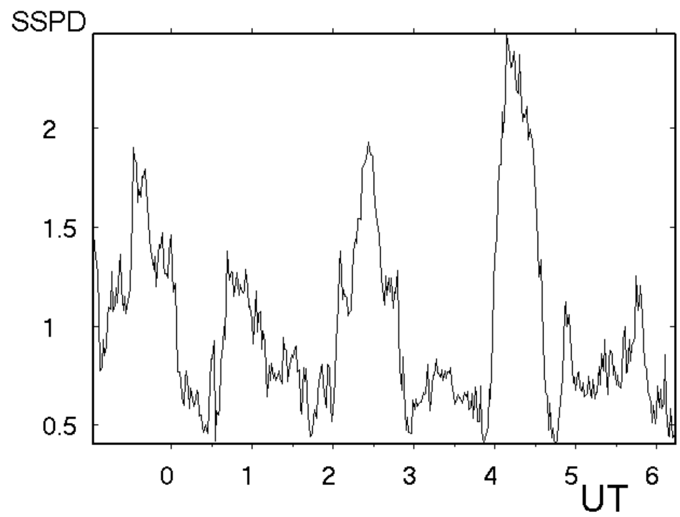

Fig. 2. Variation of the *SSPD* index (arbitrary units) in the range of 150–200 s obtained by using polarized radio emission on 07.04.2004.

each day. We have already shown that 3-min oscillations vary with a typical period of 1.0–1.5 h. For this reason we have used the Hamming window with a size of 8192 data points (or about 2.3 h) to obtain the daily spectral power. Using the Hamming window with this size was made for the better identification of the 3-min oscillations.This window was shifted along the daily data records by 30 min. The data from various days of observations were all processed by the same technique. In this work we do not use any frequency filters. Earlier we noticed that the dates with flares were excluded from the analysis, but there is slow growth of the intensity before the flares which was not excluded from the records. For this reason we cannot remove flare and long periodic processes completely. Therefore, the power spectrum increases towards low frequencies, reflecting the daily variation and flare processes. Local maxima around 3 min are visible in both figures. In addition to the maxima connected with these 3-min oscillations (peaking at $T = 174$ s in Fig. 3 and at $T = 176$ s in Fig. 4, respectively), weak local maxima connected with 5-min oscillations ($T = 286$ s. and $T = 274$ s, respectively) are seen.

The data from the Nobeyama Radioheliograph make it possible to compare the 3-min oscillations at different phases of solar activity. The minimum epoch (1995–1997) of the 22nd solar cycle is within the time frame considered in this paper, (1992–2006). We have selected the days in which sunspots were

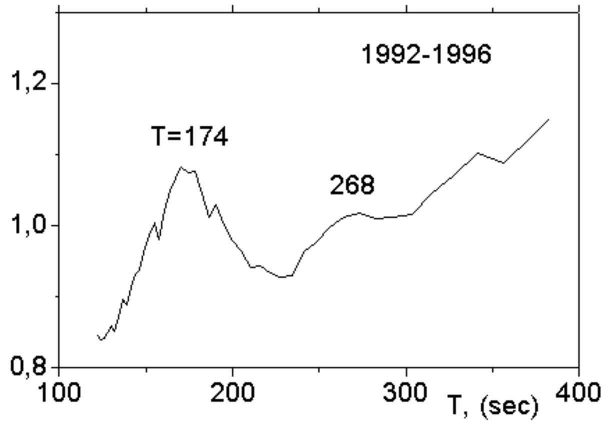

Fig. 3. The $\overline{SPD}$ index (arbitrary units) of the averaged power spectrum for the difference between the right and the left hand circular polarization of the solar radio emission during 1992–1996 according to the Nobeyama Radioheliograph at 1.76 cm.

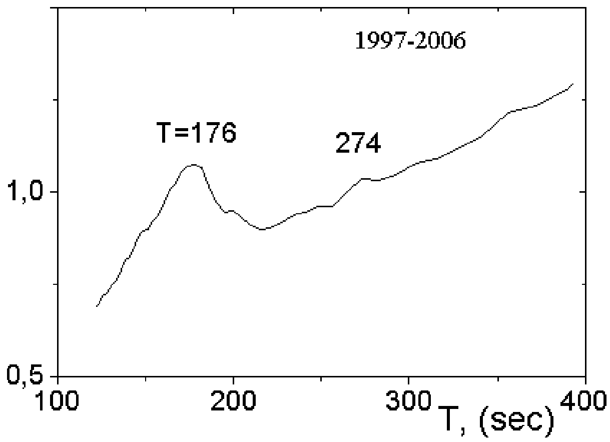

Fig. 4. The same as in Fig. 3 for the years 1997–2006.

totally absent during this minimum epoch. The total number of such days was 283. For these data we calculated the *SPD* index, which showed the absence of the local maxima in the period range from 2 to 7 min (see Fig. 5). However, even one sunspot group led to the appearance of the local maximum in the period range around 3 min. Thus, we can conclude that 3-min oscillations registered in the average correlation data we analyzed are directly connected to the sunspots.

The calculated daily values of the *SSPD* index during 1992–2006 are presented in Fig. 6. For this figure we obtained the power spectrum *SPD* for the difference between the left and the right hand daily circular polarizations. After that, to obtain the variation of the relative power of the 3-min oscillations we calculated the ratio of the *SSPD* index for the interval of periods 160–200 s to the sum of the *SSPD* indices for the interval of periods 100–160 and 200–300 s, using the expression $(SSPD_{160-200}/(SSPD_{100-160} + SSPD_{200-300}))$. To reduce the scatter of the daily values we used 30 day smoothing, which is also shown in Fig. 6. The power of the 3-min oscillations depends on the phase of the solar activity cycle. In 1994–1997 and in 2004–2006 (periods of minimum solar activity) the power of the 3 min oscillations was approximately 1.5–2 times smaller than during the period of the maximum solar activity in 1998–2004.

We can also estimate the change of the basic period of the 3-min oscillations in 1992–2006. Figure 7 shows the change of the basic period in the range of 100–220 s. The average period

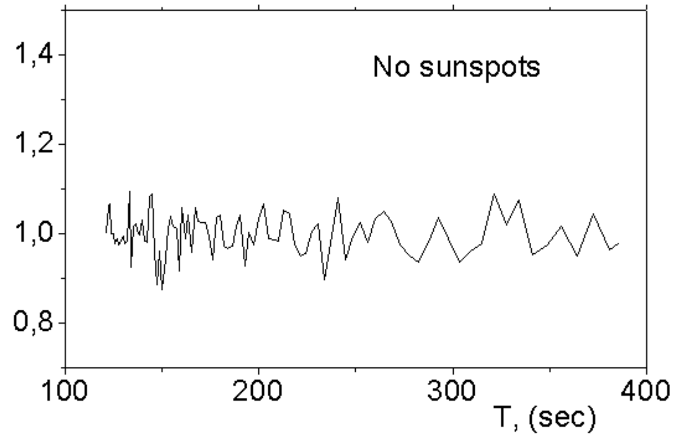

Fig. 5. The *SPD* index calculated for days without sunspots on the Sun's surface from the period 1995–1997 in arbitrary units.

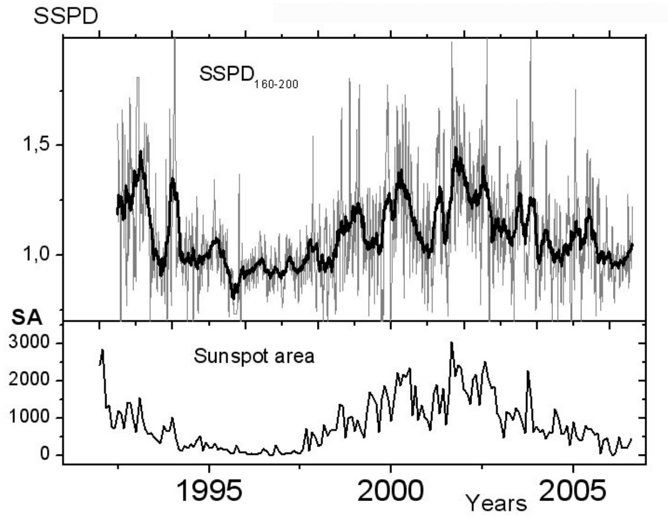

Fig. 6. (*Top*) Variation of the relative power of the 3-min oscillations in the period range of 160–200 s during 1992–2006. Daily values are represented by the grey curve. Smoothed 30-day values are represented by a thick black curve. (*Bottom*) Monthly mean of the sunspot area (SA) in millionths of the solar hemisphere (msh) (from `http://www.solarscience.msfc.nasa.gov`).

of the 3-min oscillations during the period of maximum of solar activity is about 174.4 s. The average period of oscillations during the minimum of solar activity in 1994–1997 and again after 2004, is less (about 153 s) than during the period of maximum solar activity.

5. Discussion and conclusions

The results obtained in this work show that the polarized radio emission at 1.76 cm has 3-min oscillations during a time interval comparable with the solar cycle. We have confirmed the results obtained with the Nobeyama Radioheliograph (Gelfreikh et al. 1999; Shibasaki 2001) from observations of individual active regions during only a few days.

Analysis of these oscillations at the different phases of solar activity has revealed that 3-min oscillations exist not only during maximum activity (when groups of sunspots with high magnetic field strength appear), but also during the minimum of the solar activity when there are relatively small sunspot groups. Thus, it is possible that 3-min oscillations exist in sunspots, which have

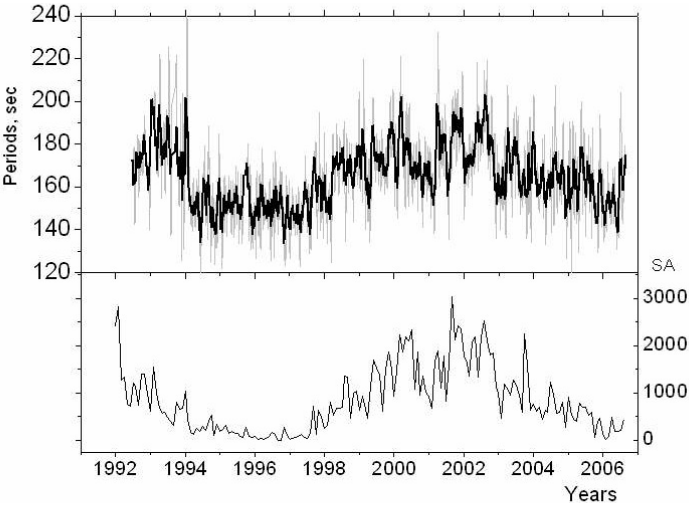

Fig. 7. (*Top*) Variation of the basic period of the 3 min oscillations during 1992–2006. Daily values are represented by the grey curve. Smoothed 90-day values are represented by a thick black curve. (*Bottom*) The monthly mean of the sunspot area (as in Fig. 6).

relatively small size and magnetic flux. Figure 6 shows that there is a linear correlation between the strength of the 3-min oscillations and the monthly mean of the sunspot areas with a coefficient of correlation $R = 0.71$.

At the same time, the average period of the 3-min oscillations changes with the phase of the solar cycle, see Fig. 7. Again, there seems to be a linear dependence between the period and the monthly mean of the sunspot area ($R = 0.6$). During maximum activity the basic periods are in the interval of 170–190 s, but during the minimum and the growing activity the basic periods are in the interval of 150–160 s. Probably these variations of the basic periods are related to the individual sunspot areas. Thus, an increase in the area of sunspots leads to an increase in the basic periods of the sunspots oscillations. However, another interpretation of the results is possible, for example connected to the variation of the number of sunspots during the solar cycle. Thus an analysis of the oscillations obtained from the polarized radio emission of the Sun can be used for the analysis of sunspot oscillations and to detail of their inner structure.

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